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ABSTRACT

Proceedings from this annual conference focused on the progress and potential of assistive and rehabilitation technology for individuals with disabilities and ways that RESNA members can make the ideas realizable. Presentations are provided on the following topics: (1) service delivery and public policy issues; (2) personal transportation; (3) augmentative and alternative communication; (4) drooling; (5) quantitative functional assessment; (6) special education, including development of an extendible below-knee pediatric prosthesis, a pediatric therapeutic playstation, art making and assistive devices, telementoring and collaborative learning for students with disabilities, assistive technology for the sports enthusiast, electronic meeting software as a planning tool for assistive technology service delivery to infants and toddlers, making mathematics and science accessible to students with blindness, and design of an assistive communication device; (7) technology transfer; (8) sensory aids; (9) wheeled mobility and seating; (10) electrical stimulation; (11) computer applications; (12) rural rehabilitation; (13) assistive robotics and mechatronics; (14) job accommodation and employment issues; (15) information networking; (16) international appropriate technology; (17) assessment of assistive technology needs for infants, toddlers, and preschoolers with disabilities; (18) universal access; (19) cognitive disabilities and technology; (20) occupational therapists; (21) Paralyzed Veterans of America Student Design Competition; and (22) Whitaker Student Scientific Paper Competition. Presentations include references. (CR)

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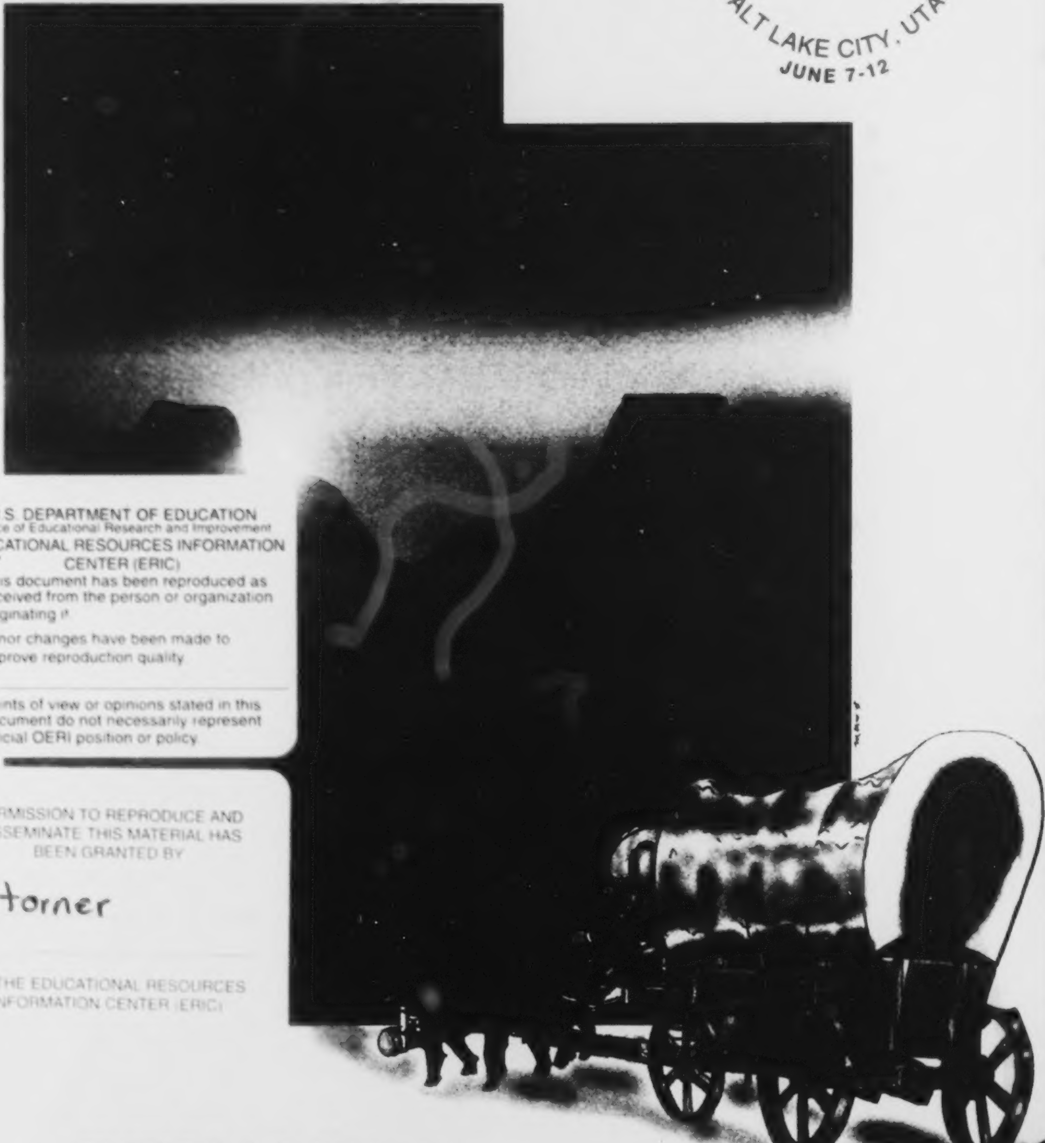
PIONEERING THE 21ST CENTURY
RESNA '96
SALT LAKE CITY, UTAH
JUNE 7-12



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RESNA '96

June 7-12, 1996
Salt Palace Convention Center
Salt Lake City, Utah

Proceedings

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PROCEEDINGS
# of the
RESNA '96
Annual Conference

Exploring New Horizons . . .
Pioneering
The 21st Century

June 7-12, 1996

Salt Palace Convention Center

Salt Lake City, Utah

Anthony Langton
Editor

Elbert Brown
Marvin Fifield
Conference Co-Chairs

RESNAPRESS

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Foreword

Exploring New Horizons - Pioneering the 21st Century

Each year, the RESNA staff, program committee, and Local Arrangements Committee strive to improve the organization and offerings of our annual conference. This year has been no exception. We have studied the evaluation data from the outstanding Vancouver conference and tried to make adjustments in schedules and activities to ensure that the 1996 conference would provide the training desired, the networking between participants, and the opportunity to see and interact with exhibitors, as well as opportunities to enjoy the Salt Lake City and Intermountain Region.

We chose for our theme, "Exploring New Horizons - Pioneering the 21st Century." This, we thought, linked the purpose of RESNA and the spirit of Utah, maximizing today's opportunities to better prepare for the future. The Local Arrangements Committee worked hard to recruit consumers to the conference and to ensure that all accommodations possible were arranged. We believe increasing consumer participation is vital to the future of RESNA. The tour to the Center for Engineering Design will provide an opportunity to see state-of-the-art and cutting-edge technology which is changing industry, human capability, and entertainment. We hope you also are able to take advantage of the local sights, pubs, haunts, and historical and recreational opportunities in the Salt Lake and surrounding areas, thus, combining the opportunity to learn, network, and have fun.

On behalf of the Local Arrangements Committee, the RESNA Board of Directors, Meetings Committee, and Staff, we welcome you to Salt Lake City for the RESNA '96 Annual Conference.

Marvin Fifield and Elbert Brown
RESNA '96 Conference Co-Chairs

Clifford E. Brubaker
RESNA President

Preface

Welcome to RESNA '96. *Exploring New Horizons . . . Pioneering the 21st Century*, the theme for this year's conference, suggests what awaits participants when they venture to the city near the Great Salt Lake. Instructional courses and morning seminars, special sessions, exhibits, and manufacturer workshops offer the best in educational opportunities. The scientific program continues this excellence with a diverse array of over 200 platform, interactive, and computer papers, presented by professionals from the United States, Canada and over ten other countries. The Second Annual Research Symposium, organized by Don McNeal and Richard Norman, focuses on Recent Developments in Neuroprosthethics: Progress Towards Functional Artificial Vision, continuing RESNA's efforts to expand research in emerging areas.

The Proceedings of the RESNA Conference attempts to share at least some of the information that participants exchanged during the presentations, activities and special events that make up RESNA '96. The many Special Interest Groups within RESNA provided opportunity for an in-depth focus on specific issues and concerns that cover almost all aspects of the rehabilitation technology field. We hope that you were one of the people actively involved in this exciting conference. These Proceedings and those from previous RESNA Conferences work to add important information to the growing body of professional literature on assistive and rehabilitative technology. If you are interested in accessing content from the Proceedings from RESNA '96 electronically, check the RESNA Home Page on the World Wide Web <http://www.resna.org/resna/reshome.htm> for information.

The Annual RESNA Conference represents the culmination of the efforts of many people. Over the past year, Conference Co-Chairs Elbert Brown and Marvin Fifield, have led an active group of over 30 Local Committee members who have helped make the conference in Salt Lake City possible. Special thanks go out to the continued work of the 1996 Meetings Committee - Aimee Luebben, Denis Anson, Kevin Caves, Carol Sargent, Corrine Carriere, and Don McNeal -- under the direction of Mary Binion, for their excellent efforts. Finally, the RESNA Office staff -- Susan Leone, Terry Reamer, Jim Geletka and the others -- have worked hard throughout the year to support the conference and all the other RESNA activities. Through everyone's efforts, participants will be able to explore new horizons at the most comprehensive rehabilitation technology conference available, while also experiencing the unique beauty and wonder of the desert and mountains of the West.

We hope that you enjoy RESNA '96!

Anthony J. Langton
Chair, Scientific Program and Special Interest Groups

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SIG-01
Service Delivery and Public Policy

A TECHNOLOGY CURRICULUM STRAND

Aimee J. Luebben
Occupational Therapy Program
University of Southern Indiana, Evansville, IN

Abstract

While many occupational therapy (OT) schools have retrofitted their coursework with additional classes in technology, other programs in OT have redesigned their curricula around a core of technology related content. This paper describes an entry level OT program in which technology was designed as an integral part of the preservice curriculum. In this professional curriculum, students spend 535 of 945 (56%) classroom contact hours in technology related content and have an additional 190 hours of outside assignments related to technology. In addition, this paper examines the extent to which the OT program addresses *Technology Competencies for Occupational Therapy Practice* (*Tech Competencies)* (1), a recent document that lists 28 technology competencies for entry level occupational therapists.

Background

Although a survey reported that 69% of responding occupational therapists had recommended technology during their previous two years of practice (2), many entry level OT schools, however, have been slow to implement instructional content in assistive technology (AT). A survey of entry level OT curricula found that half of the responding schools provide less than 20 hours of technology training, while 25% of entry level curricula provide between 20 and 50 hours, and 25% of the schools have more than 50 hours devoted to technology training (3).

Entry level OT curricula have addressed the addition of technology in various ways. The University of Wisconsin-Madison created two interdisciplinary technology specialization programs: TechSpec in 1988 (4) and InterACT in 1992 (5), while the University of Washington integrated a technology training core course with technology units in other courses into the undergraduate curriculum (6). In 1992 a new OT program was designed with technology as an integral part of the curriculum (7).

The formulation of competencies in technology has been a recent development in the OT profession. In 1993 the Technology Special Interest Section Standing Committee of the American Occupational Therapy Association (AOTA) published technology competencies, training guidelines, and areas of technology content (8). More recently, a task force appointed by the AOTA Commission on Practice disseminated the sixth draft of *Tech Competencies*. This document lists competencies in three areas (evaluation, intervention, and resource coordination) for three levels (entry, intermediate, and advanced) of both occupational therapists and certified occupational therapy assistants (1). Although the occupational therapist practicing at the advanced AT level is expected to achieve a total of 45 technology competencies, according to this document, the entry level occupational therapist should achieve 28 technology competencies and be able to assist OT practitioners at higher levels of AT competency with 12 additional competencies (1).

Objective

According to *Tech Competencies* (1), all occupational therapists should possess the competencies at the occupational therapist, entry level, upon completion of accredited OT education programs. In adding technology content to address these new competencies, existing OT schools must either find room in courses already overflowing with information or decide whether to add a technology class as a required or elective course. In a newly accredited OT program, designed with technology as an integral part of the curriculum, the objective is: To what extent does the existing program address the 28 new technology competencies.

Method

A curriculum audit was performed a) to investigate the objective, to what extent does the existing 65 credit OT program address the 28 new technology competencies, and b) to determine the number of technology related hours in the classroom.

Results

Table 1 shows the 28 competencies for the occupational therapy, entry level (1) and the systematic integration of the technology curriculum strand. In this OT curriculum, each entry level technology

Table 1
Technology Competencies for Occupational Therapy Practice (1)
Occupational Therapist, Entry Level

TECHNOLOGY COMPETENCY	COURSES
1. Assist the consumer in clarifying and prioritizing goals related to the use of AT within life roles and occupations.	320, 380, Cs, Ms, PIs
2. Screen for AT needs	320, 380, Cs, Ms, PIs
3. Evaluate the individual's functional abilities in OPAs and OPCs	315, 320, 380, Cs, Ms
4. Evaluate the individual's performance contexts	320, 380, Cs, Ms
5. Evaluate and analyze the tasks and functional demands of the context.	320, 380, Cs, Ms
6. Administer specific t assessment(s) of basic technology solutions	380, Cs, Ms
7. Interpret basic evaluation results and integrate into intervention plan, reevaluating as needed.	380, Cs, Ms
8. Coordinate evaluation of OT related AT needs with the interdisciplinary service delivery team	320, 380, Cs, Ms, PIs, 470
9. Refer individuals t other appropriate technology resources when consumer needs exceed those provided by an OT practitioner	320, 380, Cs, Ms, PIs, 470
10. Develop intervention goals for basic AT intervention.	310, 320, 380, Cs, Ms
11. Provide basic interventions which optimize the individual's functional abilities in OPAs and OPCs.	310, Cs, Ms
12. Provide intervention which optimizes the individual's performance context.	310, Cs, Ms
13. Alter and/or adapt tasks to meet the functional demands of the context.	310, Cs, Ms
14. Integrate basic AT theoretical information from OT and other disciplines into intervention plan.	320, 380, Cs, Ms, PIs, 470
15. In collaboration with the AT team, perform product trials, recommend product specifications, order technologies, install and train individuals in use, maintenance, and repair of appropriate basic AT.	151, 320, 380, Cs, Ms, PIs, 470
16. Fabricate and customize basic technology solutions as needed.	Cs, Ms
17. Describe AT information resources which link consumers with technology resources	320, 380, Cs, Ms, PIs, 470
18. Discuss the contributions of other disciplines to AT application.	320, 380, Cs, Ms, PIs, 470
19. Justify the provision of basic AT and services funding reimbursement.	151, 320, 380, Cs, Ms,
20. Actively involve consumers, their families, other AT professionals, and other service agencies in all aspects of the AT service delivery process.	151, 320, 380, Cs, Ms, PIs
21. Understand and operate within relevant AT service delivery systems.	320, 380, Cs, Ms, PIs
22. Demonstrate awareness of AT legislation in service delivery	320, Cs, Ms, PIs
23. Participate in consumer advocacy activities related to AT on an individual case level.	320,Cs, Ms, PIs
24. Describe potential roles and qualifications of members of AT teams.	320,Ms, PIs
25. Participate in AT program evaluations.	320, PIs, 470
26. In collaboration with AT team, identify measurable outcomes to justify the use and adaptation of basic AT and technology interventions.	320, 380, Cs, Ms, PIs
27. Critically analyze and apply current research related to AT.	320, 380, Cs, Ms, 480
28. Participate in basic AT research studies.	320, 380, Cs, Ms, 470

KEY: Cs=Core OPA and OPC courses (340, 341, 342, 440, 441), Ms=Media courses (330, 331), PIs=Professional Issues courses (460, 461)

covered in an average of nine classes. For each of the 17 courses (57 credit hours) which comprise the didactic portion of curriculum, Table 2 shows total contact hours, technology content hours in the classroom, as well as time spent completing outside assignments related to technology. Students spend 535 of 945 (56%) classroom contact hours and have an extra 190 hours of outside assignments related to technology. In addition, students are expected to integrate technology related information into their 1060 hours (four credits) of clinical experiences.

Table 2
Technology Related Curriculum Hours

Course Number and Name (Credits)	C	AT	A
151 Orientation to OT (1)	15	5	5
310 Applied Pathophysiology I (3)	75	15	10
312 Applied Pathophysiology II (5)	75	15	5
315 Applied Movement Analysis (3)	75	5	10
320 Professional Communications (3)	75	20	5
330 Media and Modalities I (3)	75	20	20
331 Media and Modalities II (3)	45	45	25
340 OPC I: Psychosocial Skills (5)	60	60	10
341 OPC II: Sensorimotor Skills (6)	60	60	15
342 OPC III: Cognitive Skills (3)	45	45	10
380 Professional Assessment (3)	75	75	25
440 OPA I: ADL and Play/Leisure (4)	60	60	15
441 OPA II: Work (4)	60	60	15
460 Professional Issues I (3)	30	10	5
461 Professional Issues II (2)	30	10	5
470 OT Management (3)	45	10	5
480 OT Research (3)	45	15	5
TOTAL HOURS	945	535	190

KEY: C=Contact hours; AT=AT hours; A=Assignment hours

The high percentage of AT coverage in the OT coursework can be explained by two factors in the design of this curriculum. First, when the program was originally developed, the curriculum designer utilized a systems approach to integrate technology across courses rather than adding a class or devising a core. Technology became one of eight curriculum strands (wellness, ethics, professional communication, research, cultural diversity, technology, collaboration with certified occupational therapy assistants, and professional conduct) threaded throughout the tapestry of the OT professional coursework.

The second design factor that explains the high percentage of AT coverage in this curriculum is the curriculum core, comprised of five courses (22 credit

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hours). The core of the professional coursework is based on *Uniform Terminology for Occupational Therapy-Third Edition* (*UT III*) (9), one of the documents that provided the basis for *Tech Competencies* (1). *UT III* (9) divides human function into three occupational performance (OP) features: components, areas, and contexts. OP areas (OPA) include activities of daily living (ADL), work and productive activities, and play/leisure activities; OP components (OPC) consist of sensorimotor, cognitive, and psychosocial skills; and OP contexts are comprised of temporal and environmental aspects. Two of five core courses are named for the OPAs and three for the OPCs. Since the performance of persons needing OT services varies with age and environment, lifespan and OP contexts are dimensions across the five core courses.

In addition to providing content in AT, the OT program requires students to demonstrate basic computer literacy in software applications including wordprocessing, database, and spreadsheet. In 1995 another technology related requirement was added. After discussion with the university financial aid office to determine that students can increase their loan requests for equipment that is "required" (the financial aid key word), this OT program now requires all accepted OT students to own computers. Students receive many assignments by disk or e-mail and they usually submit written assignments on disks in addition to the traditional hard copy format.

Discussion

With the thread of technology interwoven throughout the preservice educational program, this newly accredited entry level OT program should be one of the first curricula in the country to fulfill the *Tech Competencies*. Students graduating from this program will have the means to operate at the occupational therapist, entry level, in the AT service provision arena and the methods to seek additional information to move to the occupational therapist, intermediate level. In a survey (3), technology content in OT schools ranged from 0 to 73 hours in lecture format and 0 to 113 hours in lab/practicum format. With 535 classroom contact hours and 190 hours of outside assignments (a total of 725 hours of technology related information), this OT program exceeds maximum number of technology training hours indicated by the reporting OT curricula. This study shows that with the comprehensive inclusion of a technology curriculum strand, an OT program can easily modify AT content to address current and future technology competencies of the profession.

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Rehabilitation Engineering Training Program Model and Issues

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ABSTRACT

The Rehabilitation Engineering Training Program at CSU, Sacramento, is discussed. The current model, anticipated changes as a result of transitioning from substantial grant support, and issues pertaining to rehabilitation engineering education to address an evolving profession are presented.

BACKGROUND

The education of rehabilitation engineers has been a topic of interest for many years (1,11). A number of different approaches have been reported ranging from master's degree programs (2,3,4,5,8,9) to specialized internship training (6,7), and, more recently, associate degree (technician) programs (10).

The Rehabilitation Engineering Training (RET) Program at CSU, Sacramento, has been in place for six years with support from grants from the Rehabilitation Services Administration. The program has undergone a number of changes and refinements, especially more recently as it is weaned from substantial grant support. This paper reports on the preliminary results of the program, its future, and issues pertaining to rehabilitation engineering training, in general.

DESCRIPTION

The RET Program consists of 30 units leading to an MS in Biomedical Engineering and 10-12 units leading to a Certificate in Rehabilitation Engineering. Because of the loss of certain faculty and budget cuts, we have had to rely on course offerings in other departments (Biomechanics/Physical Education, Psychology, Special Education/ Vocational Rehabilitation), rather than BME courses, to fulfill the Certificate requirements. This has worked out rather well because it increases the interdisciplinary nature of the program.

The Certificate units are divided as follows: 3-4 units in neuroscience or biomechanics; 3-4 units introduction to disability and assistive technology; and 4 units of mentored field work. Mentoring is provided by an experienced rehabilitation engineer currently supported by grant funds except for the off-site Clinical Internship. The field work units consist of: (1 unit) Competency Modules in Assistive Technology (videotapes, readings, discussion, and hands-on training in the areas of augmentative communication, wheelchairs, seating systems, interfaces, and mounting systems); (1 unit) Clinical Experience (currently through the Maryjane Rees Language, Speech and Hearing Clinic at CSUS and including participation of students and faculty in the new Physical Therapy program at CSUS); (1 unit) Survey of Rehabilitation Engineering Service Delivery Sites (northern California) and Issues (requires a report of current issues in assistive technology); and (1 unit) Clinical Internship (8 weeks full time work during the summer in an assistive technology service delivery setting off campus, currently grant funded).

The grant funding also provides student stipends for approximately 12 hours per week during each semester. During this time, the students work with faculty in their research, gain clinical experience at the Maryjane Rees Clinic, or work on their own research toward their thesis.

RESULTS

The RET Program has graduated eleven students as of this writing (Fall, 1995). Of those graduates, two are in the manufacturer/supplier field, six are in clinical/ service settings, and three are pursuing PhD or MD education. By Summer, 1996, there will be four additional graduates and three continuing students. Of the eighteen total students who have been or are in the program, seven (39%) are female. We are planning to survey the graduates regarding the usefulness of their education and training experiences in their jobs. This information should be available at the presentation of this paper.

There are a number of important issues that the program faces as it transitions from substantial grant support. The first is the loss of student stipends and student support for the off-site clinical internship. The grant support has attracted high-quality students and has allowed students access to high-quality internship sites that would not normally be able to financially support a rehabilitation engineering trainee. The second is the loss of support for the rehabilitation engineer mentor who supervises the field work units. Departmental budgets do not allow for the absorption of this type of highly individualized work load. This is unfortunate because we feel that this mentoring is one of the factors that makes the program and its graduates so successful.

We believe that these issues can, to a large degree, be overcome because of some recent changes in the general Biomedical Engineering Program and because of the diversity of disability programs available at CSUS. The BME program is in the process of successfully increasing its field work (internship) placements in an expanding, local biomedical and hospital industry. Rehabilitation engineering plays a significant part in this industry (e.g., Integrated Surgical Systems, makers of the ROBODOC hip implant surgical assist, and the move of Shriner's Children's Hospital from San Francisco to Sacramento that is underway), and there are expanding opportunities for RET Program students to gain financial support and add valuable work experience to their resumes.

CSUS has educational programs in the areas of speech pathology, physical therapy, special education, and vocational rehabilitation. These programs offer course work and clinical experiences that directly involve assistive technology and service delivery issues. Interestingly enough, this is in large part due to the success that rehabilitation engineers have had in developing assistive technology products and in training other disciplines in its practical application. These resources are available to RET Program students and that will likely be used in place of the course work and field work experience that the Program requires. We are in the process of transitioning the Certificate requirements to take advantage of these resources.

DISCUSSION

Rehabilitation engineering is a profession that remains dynamic in both its coverage areas (e.g., service, research, product development in communication, mobility, restoration of function, robotics, human factors/ergonomics, etc.) and professional opportunities (jobs). As previously mentioned, rehabilitation engineers have been successful at developing a wide range of assistive technologies and at training other disciplines in systematic methods for the practical application of those technologies. This has reduced the number of job opportunities in a number of areas, most notably service delivery. Dr. Albert Cook, noted pioneer in rehabilitation engineering, has noted that rehabilitation engineering was initially highly research oriented, then became more service delivery oriented, and now appears to be heading, full circle, back to research (12). Because of these issues, it is necessary for a successful rehabilitation engineering education program to provide its consumers (students) with the tools necessary to successfully navigate the ebb and flow of the profession and the likelihood of one or more career transitions during an engineer's lifetime (11).

It is our opinion that this is best done at the master's degree level. In talking with students and industry, we have come to believe that undergraduate biomedical or rehabilitation engineering programs serve to provide advanced technicians, but do not provide the depth of engineering knowledge and the keys to life-long learning necessary to carry an engineer through his or her professional lifetime. We see a niche for rehabilitation/ assistive technologists who are likely to be more efficiently trained at the associate degree level.

We have already discussed anticipated changes to our Certificate curriculum that we think will allow us to maintain a level of depth in disability/assistive technology exposure and interdisciplinary interaction while keeping within our available resources. The CSUS BME Program is also making curriculum content changes that we believe will better serve both our RET and BME students. These include concurrent engineering, quality assurance and quality management, human performance and human factors related to medical and assistive technologies and applications, regulatory requirements and standards (FDA, FCC, ISO, CE, etc.), etc. We are waiting to see the effects, if any, that the credentialling and certification efforts of RESNA may have on the rehabilitation engineering profession, and the corresponding curriculum changes that may be needed to keep our graduates well prepared.

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THE POWERED EASEL

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ABSTRACT

The Powered Easel (Figure 1), offers an expanded sense of freedom to a very important segment of our society. The device is designed to be used by individuals who have minimal mobility of their upper extremities. The drawing surface is moved with the use of a joystick. The joystick controls two small DC motors that in turn drive a set of power screws. Although the design was undertaken specifically for one quadriplegic, complete drawings have been released for interested groups or individuals. This design produces a cost effective solution to what would otherwise be a completely custom designed and fabricated unit. This alternative is obtainable because it utilizes some flexibility in manufacturing, simple machining, and is made of readily available parts. This project would be an ideal high school shop project, providing students the opportunity to contribute their talents to the community.

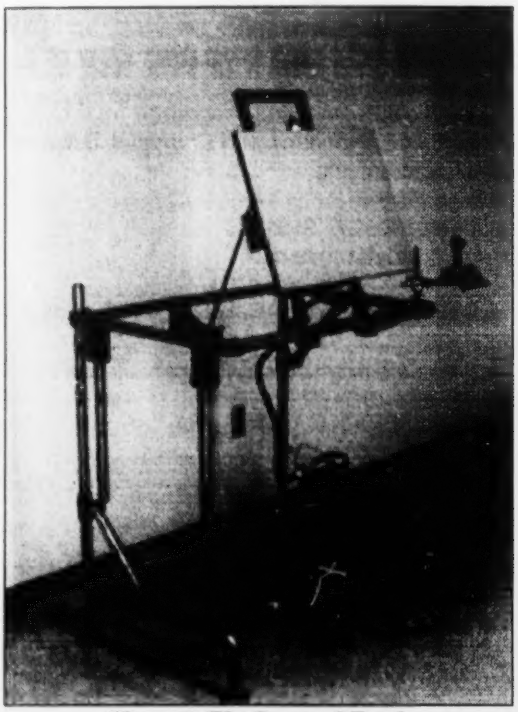

Figure 1: The Powered Easel

BACKGROUND

This project was initiated in order to assist a young artist. The specific individual became a quadriplegic a few years ago as a result of a diving accident. Before receiving the electric easel, this talented artist would draw over a very small area with a pencil in his mouth, wait for someone to move the paper and then continue drawing. Due to this dependence, even the simplest of drawings could take many hours to complete. Therefore, a device that would allow this individual to maneuver the drawing surface independently, could improve the quality of his life and those that help to care for him.

The Powered Easel, through the use of its joystick controller, allows for easy adjustment of the drawing surface. A chin operated joystick control was chosen due to its similarity to the motion controls used on most motorized wheel chairs. Therefore, a certain amount of familiarity would exist and most users could adjust to the controls very quickly. Also, by using switch components easily obtained from any electronics store, an inexpensive high amperage joystick design was incorporated.

STATEMENT OF THE PROBLEM

A portable easel composed of inexpensive components needed to be designed and built. This device needed to have an adjustable, tilting drawing surface and adjustable joystick controller so that the easel could accommodate the user where ever it was set up.

DESIGN

For this particular case the frame was made of galvanized pipe and utilizes adjustable fittings, which allow easy assembly and re-sizing. Due to a lack of upper mobility, this adjustability is important to assure proper drawing alignment. To further assist in this vertical alignment, the easel drawing surface incorporated rough adjustments by the use of tear drop fasteners (also known as key holes). This adds four vertical positions that the drawing surface can be mounted on, relative to the X-Y table.

Since this particular design of the easel was built for an individual who likes to draw outside, several other factors became important. The easel needed to be small enough so that it could fit through a standard entry door. It needed to be heavy enough so that it would not fall over when the wind was blowing hard. Finally, it needed to be portable, so wheels and carrying handles were included in the design. The drawing board and X-Y table are easily removable at the hinges, and can be reinstalled to any other frame, tabletop or bench with little trouble.

Since linear motion was desired, power screws were chosen as the method used to transmit the power to the drawing board. Large power screws were used, much larger than were necessary due to system loading. This was purely an economic design decision. The one inch diameter screw chosen, and the large pillow block bearings used to constrain the screw, were far less expensive than the smaller components actually needed.

The X-Y table sub-assembly involved the most synthesis. Once a *piggy-back* configuration was chosen for the two power screws (Figure 2), it was necessary to choose some type of mechanism that could be used to provide the linear motion needed. Linear slides are preferable but they are generally too expensive for a project of this type. Therefore, it was decided to use v-track and v-track rollers to guide the X-Y table sub-assembly components driven by the power screws.

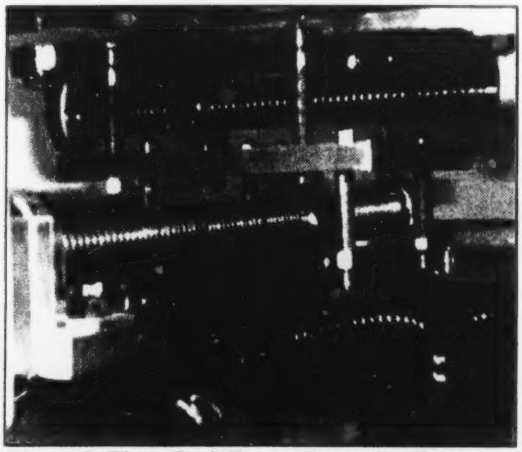

Figure 2: Piggy Back Power Screw Configuration

After the v-track roller system was established, and the desired motion had been attained, the next logical step was to determine how to deliver power to the power screws. Due to the nature of the design, large loads would not likely be experienced so very low torque, inexpensive motors could be used. This also makes it possible to use small rechargeable motors (i.e., cordless drills/screwdrivers).

The stall current of the motors selected is approximately 5 amps with normal operation requiring between 1 and 2 amps (at 12 V DC). In order to purchase a joystick controller that can handle currents of this magnitude an industrial grade joystick, costing between $200 and $300, would need to be bought. It was believed, that a much cheaper joystick could be designed using mini-lever switches.

As shown in Figure 3, all of the components of the joystick are easily obtainable and are not too expensive. The plastic housing box and the mini-lever switches are standard electrical components and can be purchased at most electronic stores.

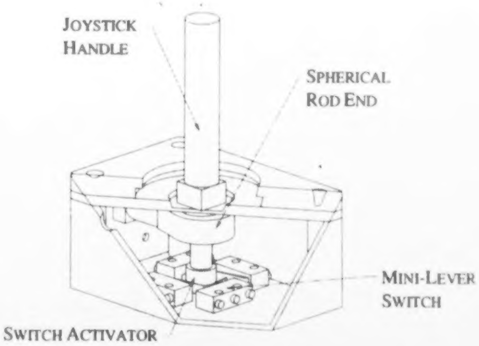

Figure 3: Joystick Components

As can be seen in Figure 2, one of the two power screws in X-Y table sub-assembly directs the movement of the drawing surface in either the X or Y direction. The lower power screw moves the drawing surface in the X direction and the upper power screw moves the drawing surface in the Y direction. A schematic of the Y-axis control system is provided in Figure 4. The joystick assembly, which is composed primarily of four mini-lever switches and a switch activator attached to the joystick handle, controls the current and polarity to the motor. When the switch activator is moved in the positive Y direction of Figure 4, by moving the joystick handle in the negative Y direction of Figure 4, the mini-lever switch completes the circuit from the battery to the motor. The motor is wired so that this polarity turns the power screw clockwise and the nut then moves down. The two limit switches are attached to a member supporting the motor and the power screw pillow blocks. When the nut engages the lower limit switch the circuit is broken and

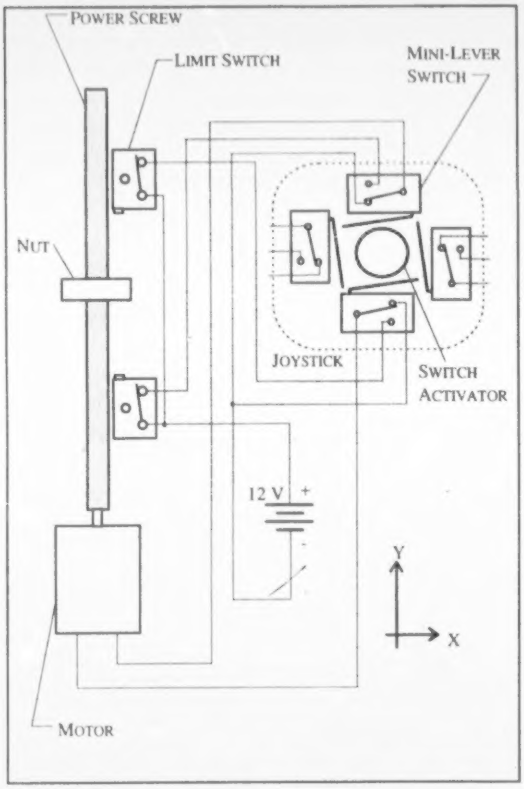

Figure 4: Easel Schematic for Y-axis Controls

power to the motor is removed. Similarly when the lower mini-lever switch is triggered, the nut moves upward until it contacts the upper limit switch. The lever switches on the left and right sides of the joystick box control the X-axis movement in the same fashion.

DEVELOPMENT

Other models of the powered easel are in the design stage. One of which is light and small enough to fit into a brief case. The idea behind the small portable powered easel is that it can easily be set up on a desktop or tabletop using a three legged frame similar to a non-powered artists easel.

Another design incorporates three axis movement (X,Y,Z) instead of just two axis movement (X,Y), and includes powered tilt adjustment about the sagittal axis. The drawing board on this three axis powered easel is made out of Plexiglas so that the user can see through it. The drawing board is controlled with puff and sip controls instead of a joystick. There is also a sonar safety switch on the z axis and tilt adjustments.

The current design is a relatively low cost solution that can be used as an inexpensive means to accomplish the intended task. This project has been completed with the intentions that anyone that wants to build a similar device will be provided with the information needed to guide them through building one. This would be a project that a high school shop class could easily complete, providing the students and the school with a great opportunity to give back to their community.

EVALUATION AND DISCUSSION

On February 23, 1995 the completed easel was delivered to the intended user. The powered easel has greatly increased the artist's productivity and has allowed him to complete his drawings by himself which boosts his sense of satisfaction. There have been no reported problems with regards to the operation and durability of the easel. While the easel was still in the lab where it was built it took a considerable amount of constant use, and after a few minor adjustments, it weathered this wear very well.

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IMPLEMENTATION OF A COMPREHENSIVE ASSISTIVE TECHNOLOGY SERVICE DELIVERY PROGRAM AS A HUB OF A REGIONAL NETWORK OF AT SERVICES.

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(1) University of Pittsburgh, (2) Northstar Health Services, Inc.

Abstract

The Pennsylvania Office of Vocational Rehabilitation has established the Center for Assistive and Rehabilitative Technology (CART). CART is a comprehensive assistive technology (AT) service delivery (SD) program. This paper describes the concept of comprehensive service delivery program, as well as the administrative infrastructure required to implement it. Benefits to the clients and vocational rehabilitation counselors are discussed. In addition, information is provided regarding the plans to further develop this SD program into a hub of a regional network of AT service providers in Western Pennsyvania.

Introduction

The Pennsylvania Office of Vocational Rehabilitation (OVR) operates the Hiram G. Andrews Center (HGA), an educational and comprehensive rehabilitation facility for persons with disabilities. The HGA Center is located in Johnstown, Pennsylvania, and provides services to clients referred from the 15 OVR districts in the Commonwealth.

Through recommendations of consumer advisory groups, the HGA Center pursued the initiative to establish a comprehensive assistive technology service delivery program in 1994. This initiative resulted in the implementation of the Center for Assistive and Rehabilitative Technology (CART). Further development of the concept of the comprehensive service delivery program, resulted in the design and implementation of CART as hub of a regional AT service delivery network for Western Pennsylvania. This paper describes the service areas which integrate a comprehensive service delivery program and the proposed organization of a regional network.

Comprehensive Service Delivery Program

Many authors (1,2,3,4) have described the implementation of AT service delivery programs. The interdisciplinary nature of the provision of AT services is evident from these publications. However, review of the literature regarding service delivery programs failed to identify a fully comprehensive service delivery program. By comprehensive SD program we refer to a service program which includes screening, evaluation, equipment procurement, training and follow up in all of the following service delivery areas: positioning and mobility; augmentative and alternative communications; computer access and environmental controls; home, school, and work site modifications; vehicle modifications and driver training; devices for visual impairments; devices for sensory impairments; orthotic devices; wheelchair repair and design of customized devices. (FIG 1)

The implementation of this comprehensive program within the existing Pennsylvania OVR system, required the development of an administrative infrastructure designed to complement the existing operational procedures of the HGA Center. Participation of numerous disciplines was required in the design and approval of this infrastructure. Disciplines included the administration of the HGA Center, vocational rehabilitation (VR) counselors, occupational and physical therapists, speech pathologists, rehabilitation engineers, orthetists, VR counselors for the deaf and visually impaired, technicians and technical advisors.

Results

A fully comprehensive AT service delivery program has been established within the PA Office of Vocational Rehabilitation.
Client services of the CART started on June 1995. By December 1995, approximately 150 clients had received assistive technology services. Feedback from clients and VR counselors regarding the quality and timelines of the services have been positive.

To accomplish the successful operation of the comprehensive service delivery program, an administrative infrastructure was implemented to interact with existing HGA Center procedures.
The infrastructure included the creation and development of:

- referral procedures (internal, external),
- client flow within CART
- clinical documentation (client information, screening and evaluation forms, progress notes, universal report formats)
- administrative documentation (charge documents, charge codes, charges per services)
- document flow within CART and HGA

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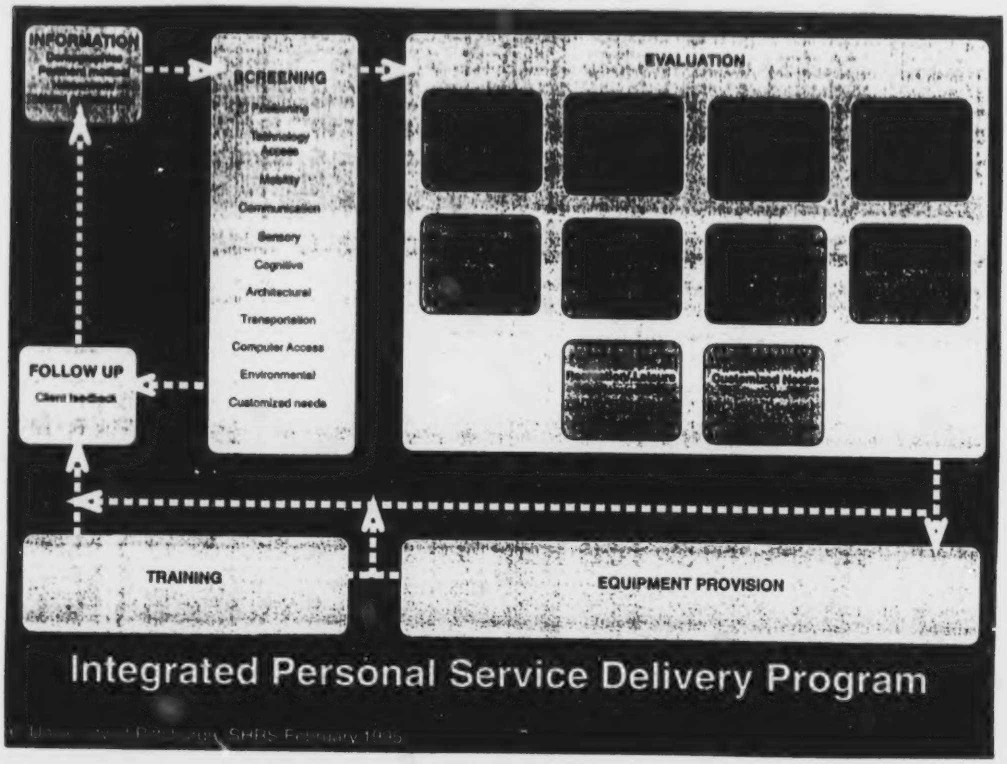
INFORMATION
SCREENING
Positioning
Technology Access
Mobility
Communication
Sensory
Cognitive
Architectural
Transportation
Computer Access
Environmental
Customized needs
EVALUATION
FOLLOW UP
Client feedback
TRAINING
EQUIPMENT PROVISION
Integrated Personal Service Delivery Program
SHRS February 1995

Figure 1. Service Delivery

- program image (mission statement, logo, brochure, new releases, local TV newsclip)

Discussion

The development of the administrative infrastructure that "blends" with the existing HGA and OVR procedures, facilitated the integration and acceptance of the new program within the HGA Center.

Disciplines and departments required to interact with the new program were made part of the planning sessions. This interaction brought significant interest and original contributions that enhanced the new program.

Availability of the CART coordinator, and standardization of AT reports enhances and facilitates communication with the VR counselors.

A comprehensive SD program is advantageous to the consumer and to the VR counselor. With all AT services offered at one location, the multiple disciplines available can evaluate the client utilizing a holistic approach. The client is able to use different technologies and experience their interactions. A comprehensive SD program provides total integration regarding the recommendation of assistive devices. Therefore, increasing consumer acceptance and effective utilization of resources and devices. To document project results, a formal program evaluation will be conducted during 1996.

Regional Network of AT Service Providers.

The comprehensive service delivery program described above, represents Phase I of the project to implement a regional network of service delivery providers in Western Pennsylvania.

Phase II of the project involves the development of local networks of AT service providers in conjunction with services provided by CART as the hub of the

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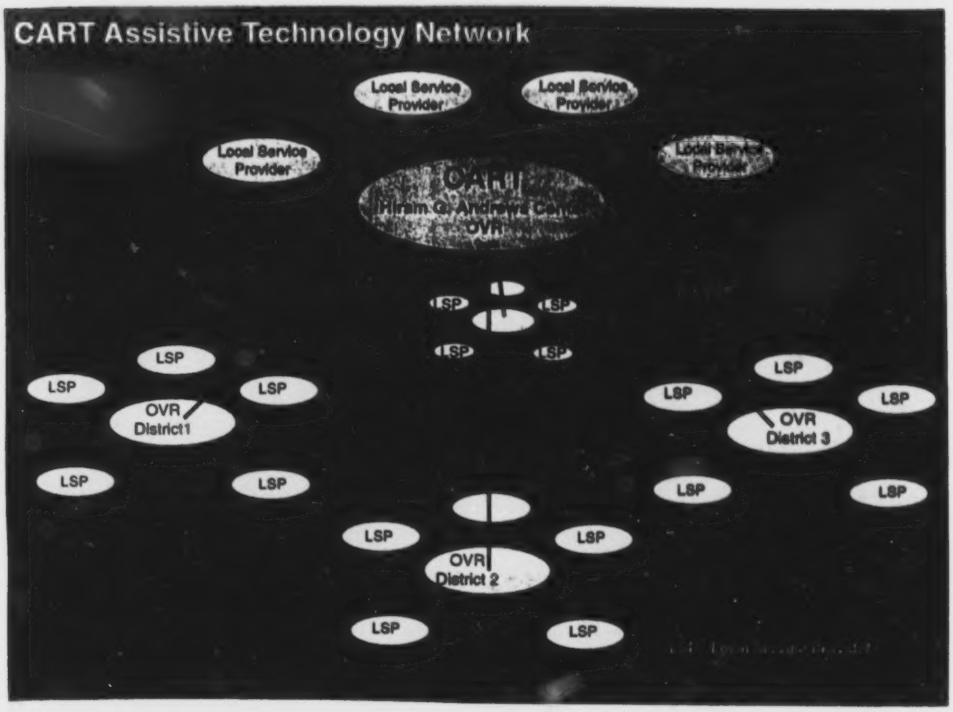
CART Assistive Technology Network
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OVR District1
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Figure 2. Network

network. Phase II of the project is planned to be implemented in three years.

At the conclusion of Phase II, six VR districts in Western Pennsylvania will be actively involved in the AT service provider network. Existing service providers in each VR district will be integrated to the network, organized according to the Inter-Agencies Service Delivery Model described by Letechipia (4). Within this organization, CART will play a significant role by providing AT services beyond the capailities of the existing local network. Full implementation of the network will provide a comprehensive service delivery program, as described above, to all six participating VR districts. Figure 2 illustrates the AT network concept.

Acknowledgments
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STATE-LEVEL ASSISTIVE TECHNOLOGY ASSOCIATIONS: COOPERATION AND COLLABORATION ON A LOCAL LEVEL

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ABSTRACT

State-level assistive technology associations are proving to meet the networking and informational needs of professionals in several states. Five state assistive technology associations were interviewed to determine their history, structure, benefits and transformations. Their accomplishments towards advancing assistive technology in their states and their struggles to remain vital membership-based associations are recorded.

BACKGROUND

In the late 1980's, rehabilitation engineers, therapists, educators, and rehabilitation counselors in several states were looking for information, for ideas- for other professionals with whom they could share their experiences and relate problems both technical and administrative. While RESNA provided a forum for information exchange and networking on a national level, it did not concentrate on state issues, and it could not bring people together more than once a year. At least five such states created associations to meet these needs.

OBJECTIVE

Now that these state associations have had at least 5 years to develop, we can seek to understand them both as a whole and individually. Collectively, we will see what role they have played in meeting the needs of assistive technology professionals. Individually, we will learn from their novel approaches and successful practices.

METHOD

Through interviews with founding members, I gained an understanding of the state of the profession at the time and of each association's early years. Follow-up interviews with current board members provided up to date profiles along with significant developments in the history of the associations.

RESULTS

Five states responded to requests for information on state assistive technology associations, defined loosely as professional and consumer associations that gather together people interested in assistive technology. While they may be tied to other associations, they are not dependent on service provider organizations or grant agencies for their existence. Thus these associations are all volunteer-based and independent.

The five states are Ohio (Ohio Rehabilitation Technology Alliance, ORTA), Minnesota (Minnesota Assistive Technology Consortium, MATC), New Jersey (New Jersey Coalition for the Advancement of Rehabilitation Technology, NJ CART), Iowa (Iowa Rehabilitation Technology Alliance, IRTA) and Wisconsin (Wisconsin Society for Augmentative and Alternative Communication, WISSAAC). The last association is different in nature, being a state chapter of USSAAC, the United States Society for Augmentative and Alternative Communication, but is included here as its meetings cover a broad area of assistive technology and members are from a variety of professions. The Iowa group is also included although it ceased operating in 1994.

Beginnings

In states where just a few people were providing assistive technology services, a few familiar professionals would get together in a bar or restaurant and talk shop. Brainstorming would happen, stories would be swapped and ideas proposed for better service delivery all around. No doubt this same scene happened all around the country (as it did in Colorado, although no formal association was formed in that state). What brought those few people from a social gathering to an association with 501c3 (non-profit) status was having a few motivated people who expanded the group's desire to spread the then still relatively new knowledge of assistive technology to other people. Other goals included finding referral sources, finding local professionals who could do follow-up work, and looking for new employees. What supported them was usually one organization with staff interested in attending and organizing meetings. This lead organization typically did the mailings and acted as a recipient of mail and telephone calls.

Non-Profit Status

In order to gather fees and have a budget, these groups had to find a way of getting 501c3 status. NJ CART and IRTA have their 501c3 independently, WISSAAC is a state chapters of a national association (USSAAC), ORTA is a division of ORA, the Ohio Rehabilitation Association, a state chapter of the National Rehabilitation Association. MATC does not have this status as yet, having funds channeled to an independent living center which acts as fiscal host and provides administrative support. However, the group is considering affiliation with its state chapter of NRA as well. For Ohio, becoming a division of ORA was natural, as many assistive technology professionals attended the annual ORA meeting as a way of advertising their services to rehabilitation counselors.

Structure

Once other people were invited and membership grew, the groups started to become more structured--with mailing lists, set meeting dates, topics and agendas. Two started out with meetings every month, later moving to 4 or 6 per year. Other groups kept to 4 meetings per year, with one having only an annual conference. Initially, due to long travel distances (especially in rural states), the meetings tended to be all day. Fees vary from no fee to $36 (the no fee made possible by the Tech Act organization). Member benefits consist mainly of free attendance at meetings, along with additional items such as a newsletter and member directory.

MATC has a unique structure that began in 1992, when it split up into 5 geographic regions. The existing assistive technology liaisons within the state's Division of Rehabilitation Services provided host facilities for MATC's regionalization, while about $2,000 and staff time on the board (from the state Tech Act organization) provided administrative and overall support.

Typical membership and attendance at meetings included: ORTA (120/40), MATC (1,000(mailing list)/10-100), NJ CART (80/20), IRTA (75/15), and WISSAAC (85/50(annual conference)).

Relationship With Other Associations

Surprisingly, WISSAAC and ORTA are very independent of their parent associations, with no specific guidance and little communication with the national associations. Few WISSAAC members are USSAAC members, although all ORTA members must belong to their state association. As for possible ties with RESNA, ORTA, MATC, and NJ CART each tried to encourage RESNA to start state associations, but found no interest.

Meeting Content

Activities include tours of hosting facilities, case studies, product demos, national conference reports and round-the-table networking and announcements. A meal is always included, with networking continuing all the while. Business meetings, to discuss committee activities or to set upcoming meetings, are either held that day or as entirely separate meetings. There have been joint meetings, held, for example, with the state USSAAC chapter, and annual conferences have been organized, usually with another organization such as a university. In addition, MATC's very structure also affects its meeting content. While the vitality of each regional chapter varies, the interaction of local service providers has been very helpful to some, allowing for very specific discussions of equipment and funding needs.

Problems Faced / Changes Since Inception

Almost all of the associations went through a time when the core few people who started the group rotated through the board positions. It has been difficult for these small organizations to draw additional members who will take on responsibilities and leadership positions. Related to this problem is that of staff getting time off from their employers to organize and attend meetings. One Tech Act staff person reasoned the importance of contributing time by saying that, although her organization is being re-oriented away from service delivery and towards systems change, increasing awareness of technology and getting professionals to know each other and cooperate is part and parcel of grass-roots systems change.

Other problems mentioned included trying to attract members from distant geographic areas, and not having anything outside of the meetings to keep members connected. The first problem was addressed creatively by MATC, although they also report the down side, which is less interest in statewide meetings, and a loss of momentum by a few regional chapters. Groups have also rotated meeting sites around the state. The second issue of connectedness has been resolved somewhat through newsletters, on-going committees or teams, and on-line services. Each of these solutions, however, inevitably demands additional time from members. The on-line solution makes use of a Department of Human Services free on-line service that is already being used by people with disabilities and rehabilitation professionals. In addition to a discussion area, there will be interactive on-line databases that the association hopes its members will help to update.

DISCUSSION

Clearly, the need for information, whether on products, techniques, or applications, is available from many sources. The contact with other service providers and the awareness of the services of other organizations is one need, however, that does not seem to be met through other means. Other possible unique applications include group action on legislative issues, information dissemination on quality assurance to those outside of RESNA, and assistive technology awareness to local professionals.

For a state without such an association, is it worth the effort to start one? The relative importance of cooperation among service providers and between providers, researchers, students, suppliers and manufacturers, would determine the need for such an association. Undeniably, there is something about having met and worked together with those you compete with and those you serve that breaks down barriers.

As competition for scarce resources increases, will we close off and go the way of the commercial world, or will we keep the tradition of collaboration that makes our field so attractive and so worth working for?

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A search of RESNA proceedings back to 1989 yielded no articles on these state associations, and the author is aware of no other publications with such articles.

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COMPARISON OF COSTS INVOLVED IN MAKING WORKSITE ACCOMMODATIONS

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ABSTRACT

The cost of worksite accommodations is a concern of employers, referral agencies and funding sources. A cost analysis study of worksite accommodations completed by rehabilitation technology specialists was compared to accommodation information available from the Job Accommodation Network reported by employers. The comparison used mean cost data to indicate cost for accommodations and to determine similarity of findings. Results showed surprisingly similar cost estimates.

BACKGROUND

The use of worksite or job accommodations as a strategy to address the retention and hiring needs of individuals with disabilities is becoming a common practice with a growing number of employers. The Job Accommodation Network (1995) reports that the number of requests for information and technical assistance on accommodation needs was 92,644 in 1993-94, an increase of approximately 26% since 1991-92. Providing worksite accommodation services represents an important, although still somewhat small portion of rehabilitation technology service delivery activity (CRTS, 1994). Perceptions regarding the (high) costs of accommodations and difficulty in securing adequate reimbursement for services are suspected as reasons why greater use of worksite accommodations has not occurred.

Determining approximate costs for making accommodations for individuals with disabilities is an important concern from employers and agencies working with individuals with disabilities. Rehabilitation technology practitioners in particular are very interested in establishing a common awareness of what worksite accommodations typically cost to assist them in securing necessary funding and reimbursement for services rendered.

Extensive work done by the Job Accommodation Network has helped to gather useful data from employers on their worksite accommodation activities. JAN (1995) reported that the typical accommodation cost for most companies (78%) surveyed was less than $1000. Reports such as these suggest that the cost for making accommodations for workers with disabilities can be relatively inexpensive.

Information in Table 1 indicates the breakdown of accommodation costs reported by employers.

Cost of Accommodation (N=367)	
Cost	**Percentage**
No Cost	19%
Between $1-$500	49%
$501-$1,000	10%
$1,001-$1,500	4%
$1,501-$2,000	4%
$2,001-$5,000	9%
Over $5,000	5%

Table 1: Job Accommodation Network Cost of Accommodations (10/94-12/94)

Initial impressions of this data tend to suggest that the vast majority of accommodations are actually very low in cost. Questions remained however as to whether these estimates took into account costs such as evaluation, research and development and other services. Follow-up survey questionnaires used to gather information from employers do not attempt to gather this type of specific information. It also appeared uncertain if the time and effort of engineering and technical staff was considered.

Actual costs of worksite accommodations can be difficult to determine. Many of the costs, such as time involved with evaluation and research and development, are not always accurately accounted for, even by rehabilitation technology specialists themselves. Many rehabilitation technology specialists who provide work site accommodations fail to maintain a detailed record of the staff time involved. This is likely to be more common in situations where technology specialists are employed by programs and agencies where itemized fee-for-services accounting is not required. It is also possible that there may be a tendency to underestimate the cost of accommodations, possibly in an effort to present rehabilitation technology services in a (more) favorable cost/benefit position or to avoid some charges to be more likely to receive funding approval to implement the necessary changes.

The Worksite Accommodation Special Interest Group (SIG-14) initiated a survey in the Spring of 1995 to gather additional information to address some of these concerns. The *Cost Analysis Survey* involved an in-depth analysis of the time and effort used in completing worksite accommodations to: determine accurate cost of worksite accommodation; breakdown costs of accommodations to identify any hidden costs; estimate time/effort involved; identify sources of funding; and to develop a profile of rehabilitation technology service providers.

The initial survey effort was completed in collaboration with the Center for Rehabilitation Technology Services (CRTS), the Job Accommodation Network (JAN) and the RESNA Special Interest Group on Worksite Accommodations (SIG-14). A survey form was developed to collect cost information on three aspects of worksite accommodations: evaluation, implementation and follow-up activities. This three part analysis was used primarily to determine if there were (significant) staff and other resources involved in evaluation or follow-up activities which were not being reported in the overall cost estimates for accommodations. The survey form also attempted to collect accurate time/cost estimates by requesting detailed reporting of units of service for specific technology services (e.g. staff time, mileage, etc.), quantity of units (e.g. 2 hours, 25 miles, etc.) and cost per unit (e.g. amount charged per hour, mile, etc.).

The survey was mailed to 114 members of the SIG-14 Worksite Accommodation Special Interest Group. Twenty-seven complete surveys were returned, from eight different service providers. Preliminary data from this survey was reported in a Special Session at the 1995 RESNA Conference. In this presentation, results were given, however there has been no formal reporting of the findings. Due to the limited sample size, caution was advised in interpreting these findings independently without further corroboration. Comparison of this data with information available from the Job Accommodation Network was suggested as a method to determine if the findings would be comparable to those gathered from employers.

OBJECTIVE

Through the comparison of the survey findings with data collected by the Job Accommodation Network, this research sought to determine if any (significant) differences exist in estimates of the cost of worksite accommodations between the two sets of data.

METHOD/APPROACH

For the purpose of this comparison, only those cases which involved both evaluation and implementation phase cost

estimates have been selected. This, along with the removal of accommodations provided in a setting operating on a flat rate funding basis, reduced the original sample to only seventeen cases. Information on follow-up costs was also not included since the amounts cited were minimal. For purposes of this comparison the mean costs of accommodations from each source was used. The survey form also investigated who was providing the technology services, source of funding , however this data was not used since comparable information is not available in the JAN data. The cases and data elements selected were felt to provide the best comparison to reported employer costs in the JAN cost information.

RESULTS

Despite differences in the sample sizes and manner that data was collected, the cost of accommodations were more similar than expected. Findings from the *Cost Analysis Survey* suggest that the average cost for worksite accommodations, including evaluation and implementation costs, was $1,503. Recent quarterly report findings (10/94-12/94), which are shown in Table 2, show slightly higher costs with the mean cost increasing to $1,631.

SIG-14 Cost Analysis Study		JAN Data
Evaluation	$461.00	
Implementation	$1,042.00	
Totals	**$1,503.00**	**$1,631.00**

Table 2. **Comparison of Cost Accommodation Findings**

Further comparison with other JAN data shows that the mean cost for all job accommodations since October 1992 was $1,057.

DISCUSSION

The purpose of this comparison was not to determine which set of figures was more accurate. The data

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available to make such an in-depth comparison is not readily available. It is also important to acknowledge that "average costs", while being a convenient way to view cost data, can tend to be misleading. The severity of the disability and the extent of functional impairment have not been factored into either of these sets of figures. It seems apparent that the costs for making a job accommodation for an individual with a severe disability, whether to retain someone who has been injured or to hire a new employee, will likely be more costly than someone with only minimal functional impairment.

Initially, in looking at the data in the JAN report, there was some concern as to whether employers would provide a comprehensive enough report to capture all the costs of making accommodations. An advantage of the *Cost Analysis Survey* was the level of detail that was collected in multiple areas. Expectations were that the mean costs of $1,503 would have been higher than those reported to JAN by employers. The similarity of the cost estimates would tend to suggest that adequate attention is being given by employers to reflect the full array of costs.

It is still uncertain however, whether sufficient consideration is given to the involvement of rehabilitation technology specialists in accommodations reported in the JAN data. A difference in the two survey efforts that may be worth further investigation is in the way that rehabilitation engineers and other technology specialists are accounted for in the evaluation phase of accommodations. According to JAN, the time spent by technology specialists doing evaluation is considered to be part of general consultation services to the employer and would not be typically counted as part of the accommodation costs for a specific individual.

There was no attempt within the scope of this paper to investigate the distribution of functional limitations and disability profiles within the various categories reported. It is important that additional research consider various outcomes measures and factor in severity of disability. Cost data alone can inadvertently be used set limits which can impede the quality of services and impact outcomes and customer satisfaction.

Determining the actual cost/benefit of worksite accommodations, as well as other rehabilitation technology service interventions, will increase in importance as the field moves toward greater cost controls under managed-care programs. Information being collected by the Job Accommodation Network and work of the SIG-14 Worksite Accommodation group provides an excellent reference point to continue the investigation. A complete report of the total *Worksite Accommodation Cost Analysis Survey*, including analysis of additional cost and funding factors along with a profile of service providers, is available through the Center for Rehabilitation Technology Services.

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JOB RESPONSIBILITIES OF REHABILITATION ENGINEERS IN VOCATIONAL REHABILITATION AGENCIES

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ABSTRACT

The role of rehabilitation engineers in vocational rehabilitation agency settings is essentially undefined in spite of years of debate and discussion. To address this problem, a dialogue was opened at a RESNA conference in 1993 to begin to define the job duties of individuals functioning as rehabilitation engineers in vocational rehabilitation agencies across the country. A survey instrument was developed as a result of this dialogue; data from the survey is discussed.

BACKGROUND

In 1992, the Center for Rehabilitation Technology Services sent a survey to all 81 vocational rehabilitation (VR) agencies in the United States. Of the agencies surveyed, 61 responded. This survey found that "there were over 60 different job titles held by the 121 individuals who completed the Rehabilitation Engineer Profile."(2). Attigupam (1) reported a breakdown of time spent in various activities by persons functioning as rehabilitation engineers (rehabilitation technology providers) based on the CRTS survey. Activity areas identified were: Management/Administrative Activities; Service Delivery; Community Service; Training; Research; and Other.

OBJECTIVE

The objective of the research is to more fully describe the job duties of rehabilitation engineers by describing their job duties in terms of (1) the amount of time actually spent doing the tasks, and (2) the relative amount of importance the respondents assigned to the tasks.

METHOD/APPROACH

A focus group was convened at a RESNA conference; the group identified specific rehabilitation engineering job tasks they performed in the areas of: Management/Administration; Service Delivery; Community Service; Training; Research; and Other. These duties were listed, broken down into job tasks, and compiled into a questionnaire sent to 215 individuals who were identified as rehabilitation engineering service providers by VR agencies nationwide. Some of these providers were VR employees; others were outside contractors who provide rehabilitation engineering services to VR agencies. VR employees were asked to account for all of their time; contractors were asked to account for only the time they spent working with VR clients. They were asked which of the listed job tasks they performed; to identify how much of their time was spent performing each job task, and to identify how important they felt each job task was to their job as a rehabilitation engineer. Reminder post cards were sent out three months after the questionnaires in an attempt to improve the response rate.

For each task, each person responding was asked (1) Is this task part of your job? (yes/no); (2) What relative amount of time do you spend on these tasks? (5 point Likert scale); and (3) What is the relative importance of this task to you as a rehabilitation engineer? (5 point Likert scale). Finally, each respondent was asked what percent of his/her total time was spent on tasks in each of the major categories. All responses are confidential and anonymous.

RESULTS

Each of the major job task categories was broken down into job tasks as specified by the focus group. Within each major category, an "other" category was provided in case there was a job task that clearly fit within the category, but was not covered in any of the more specific job task descriptions. Additionally, a sixth major category of "other" was included in case there was a major job area being performed by rehabilitation engineers that was not identified by the focus group.

A total of 36 VR employees, 29 VR contractors, and six who did not specify their status responded to the questionnaire (out of 215 mailed out) for a return rate of 33%. Some individuals skipped portions of the questionnaire; in these cases, the questionnaires were used and the omitted sections were treated as missing data.

There were very few responses in any of the "other" categories. In the Management/Administrative section, six respondents (five VR employees and one contractor) listed "other" tasks; in the Service Delivery category, two respondents (one VR, one contractor) listed "other" tasks; in the Community Service category, one VR employee listed an "other" task; in the Training category, one VR employee listed an "other" task. Under the Research category, no "other" tasks were listed. Additionally, the major job category "Other" was not used by a single respondent.

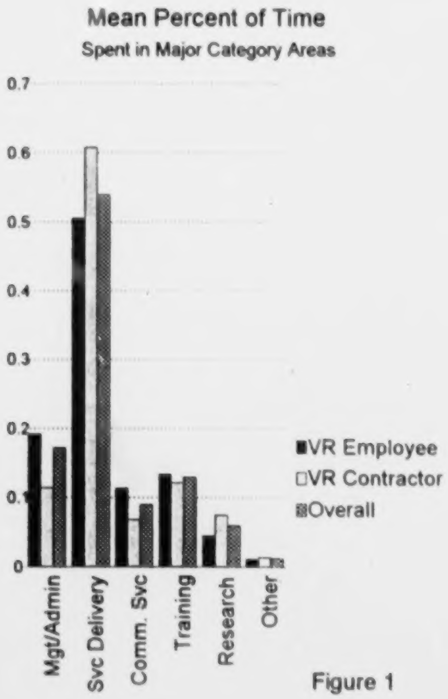

Figure 1

As illustrated by figure 1, over half of rehabilitation engineers' time is spent in service delivery (54% overall; 50.6% for VR employees; 60.8% for contractors). Management/ Administrative tasks require the second largest amount of time (17.1% overall; 19.2% for VR employees; 11.4% for contractors). Training is next, at 12.9% overall (13.3% for VR employees, 12.1% for contractors). This is followed by Community Service (8.9% overall; 11.3% for VR employees; 6.8% for contractors) and Research (5.9% overall; 4.5% for VR employees; 7.5% for contractors). Even though none of the respondents utilized the "Other" major job category to specify any tasks, respondents stated that they performed other duties 1.2% of their time (1.1% VR employees, 1.4% contractors) overall.

Without exception, rehabilitation engineers indicated that they need more time to devote to all of their job tasks. In all job task categories, VR employees and contractors stated that the importance of the task transcended the amount of time they spent doing the task. While all tasks were stated to be more important than the time spent doing the task, some of the "time deficits" were greater than others. The most notable time deficits were as follows:

Major Task Area	Job Duties with the Greatest Time Deficit
Management/ Administrative	Program Evaluation
Service Delivery	Fabrication/Construction, Follow-up
Community Service	Public Relations, Funding
Training	Inservice/preservice, professional development
Research	Product development

DISCUSSION

Upon initial inspection of the data, there are two areas that are worthy of note. First, it seems that the instrument is an accurate compilation of the job duties of persons who function as rehabilitation engineers, both as VR employees and as VR contractors. The second item of interest is the fact that all of the tasks in the instrument were found to be more important than the time available to perform them by the respondents. In developing the questionnaire, the researchers felt that there would be some areas that were "annoyance" tasks (i.e., tasks that the rehabilitation engineer routinely performed, but which the engineer felt should be performed by some other staff person, or not at all). However, this was not the case on any task listed on the questionnaire.

While there are some differences (between VR employees and contractors) in specific job task areas, the overall picture is the same—all of the duties listed on the questionnaire are important tasks for rehabilitation engineers. They currently perform these tasks; they feel that they are all important to the degree that they should be devoting more time to all of them; and they didn't list a significant number of tasks in the "other" categories. This would seem to indicate that the instrument would be an appropriate resource for the development of a comprehensive job description for a rehabilitation engineer, whether the engineer works for VR or is an outside contractor.

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CONTINUOUS QUALITY IMPROVEMENT OF REHABILITATION TECHNOLOGY SERVICES IN VOCATIONAL REHABILITATION AGENCIES

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ABSTRACT

A continuous quality improvement effort for rehabilitation technology programs in Vocational Rehabilitation agencies has been developed and is being piloted in three agencies. This effort focuses on customer satisfaction and the effectiveness and efficiency of services provided. A guide explaining the process has been written which includes surveys to measure satisfaction and perceived effectiveness of the services provided. These data are collected from counselors, clients, and employers (when they are involved). A form for collecting cost efficiency data is also included. These data are collected by the technology provider. Revisions will be made based on pilot test results and the Guide will be made available to all VR agencies in late 1996.

BACKGROUND

There has been considerable interest in the rehabilitation technology field in determining which service delivery models are the most effective and efficient means of providing these services. However, since most rehabilitation technology programs were not developed according to a specific model or pattern, making meaningful comparisons across programs is extremely difficult, if not impossible. If comparisons across programs are not reasonable at this time, another method to assist agencies in determining whether their service delivery approach is meeting the needs of the customers is warranted. One alternative is for agencies to conduct a self-assessment of the efficiency and effectiveness of their programs. Since many Vocational Rehabilitation (VR) agencies are becoming involved in quality improvement efforts, an extension of this effort into the rehabilitation technology area appears to be a logical mechanism for assessing program efficiency and effectiveness.

One of the most difficult aspects of conducting a continuous quality improvement process is the development of effectiveness measures. It is especially difficult in the rehabilitation technology area where direct measurement of outcomes are not available. In an attempt to assist rehabilitation technology programs in VR agencies to assess the quality of their programs, the Center for Rehabilitation Technology Services (CRTS) developed a continuous quality improvement process with effectiveness, efficiency, and satisfaction measures which agencies could adapt for use in their own programs. This process is being piloted in three agencies to determine its adaptability and usefulness in VR agencies.

OBJECTIVE

The major objective of this study is to determine whether the continuous quality improvement process developed for rehabilitation technology programs in VR agencies can be adapted and effectively used by these agencies to improve the quality of their programs.

METHOD

CRTS staff hired an expert in total quality management and an expert in business administration to work with CRTS staff to conceptualize an approach to continuous quality improvement specifically for rehabilitation technology services programs in VR agencies. Definitions of terms to be used in the process were established first. A thorough review of the literature was then conducted to avoid replication of already existing procedures and instruments and to determine how best to measure outcomes of rehabilitation technology services. The process was conceptualized and measurement instruments were developed. Throughout the process, focus groups were held to ensure that the instruments and procedures were appropriate and practical. All instruments were periodically mailed to selected technology providers for review. Comments were incorporated into various drafts of these instruments. CRTS staff and consultants went to each pilot site for further input on the entire process. Final revisions were made prior to initiation of the project.

A Guide to Assessing Rehabilitation Technology Program Quality Measuring Satisfaction, Effectiveness, and Efficiency was developed to explain the process. The process is currently being piloted in three agencies. During the pilot phase, each participant attended a training session to learn about the process. The Guide was provided at that time to each participant. The data collection process was explained and a set of customized forms and return envelopes were provided to everyone involved. The instruments, training, and data collection process will be refined and the Guide will be revised based on feedback received during the pilot phase.

APPROACH

A good definition of quality considers both outcome and process (1). Both of these aspects of quality define the value of the service. This definition can be expressed as an equation: Value = Quality/Cost. The operational definition of quality in this definition is satisfaction times effectiveness ($Q=S \times E$). Quality can be understood and improved only in relation to cost. Changes in cost that do not maintain or improve quality do not add value. In programs which offer exceptional value, customers get appropriate products and services when they need them and the processes people use to design, deliver, and maintain products and services are efficient. The value equation was used as a guiding principle in the development of the quality improvement process.

As a part of the quality improvement process, data must be gathered which can be used to determine the value of the services offered. Three types of data are being gathered by rehabilitation technology staff: efficiency, effectiveness, and satisfaction. The efficiency component focuses on direct costs that the rehabilitation technology provider can control, staff time, and client elapsed time in the rehabilitation technology process. The technology service provider tracks these data and also records some demographic information about each client. Demographics such as degree of functional limitation, gender, education, age, work status, etc. are used in the final analysis to weight the cases. The effectiveness component focuses on the extent to which rehabilitation technology increased the functional capabilities of the person served. At this time, direct measurement of outcomes in rehabilitation technology are not available. The next best method is to have the customers rate effectiveness. Satisfaction is relatively easier to measure. Research has identified the service components which have the most impact on customer satisfaction (2, 3). Eleven components of service have been selected for use on these satisfaction rating forms. Effectiveness and satisfaction are being examined through the use of surveys to be completed by clients, rehabilitation counselors, and employers (where appropriate). These surveys are mailed within 30 days after services have been delivered. Efficiency, effectiveness, and satisfaction data are then analyzed. Since continuous quality improvement uses a systems approach, all outcomes are considered important. The focus is on what in the system allowed this to happen, not who allowed it to happen. Through this system, services can be continuously improved.

During the pilot study, completed efficiency, effectiveness, and satisfaction forms will be mailed to CRTS for analysis. Preliminary analyses are conducted and sent to the participating agency. Additional analyses are conducted at the direction of the agency. These data will not reported by CRTS in any publications. CRTS staff are interested in the viability of the process and will only report on those issues. Participating agencies are not identified to other agencies verbally or in written reports. At the conclusion of the pilot study, a final meeting with agency staff and CRTS staff and consultants will be held to evaluate the process. Revisions to the quality improvement process will be made based on this and other input gathered during the pilot phase.

DISCUSSION

The pilot phase has just begun thus, some comments can be made relative to the development of the process, but little can be said about its usefulness or how well it can be adapted to fit individual agency needs.

Developing a continuous quality improvement process for rehabilitation technology programs proved to be very challenging, especially since it is being developed for use by others. The philosophy of continuous quality improvement suggests that these efforts be developed as a result of a commitment to improve the value of their services. Leaders then involve everyone and quality measurement instruments are developed by those involved in the process. If agencies choose to use the process designed by CRTS, this normal flow of events is changed. The process and the measurement instruments have been designed by someone outside of the agency. Typically, the development of measurement instruments is difficult for staff due to lack of expertise or time to develop appropriate instruments. As a result, the process frequently falters at this point. CRTS decided that the development of instruments which could be adapted by individual programs may help agencies overcome this obstacle to the implementation of a total quality improvement process. Instead of having to completely develop these forms, rehabilitation technology programs are encouraged to customize these instruments thus staff are involved but much of the tedious work has already been done.

As previously mentioned, measurement instruments are difficult to develop. This is especially true in the effectiveness area since outcome measures for rehabilitation technology services have not been developed. Compromises had to be made in this area. Effectiveness is rated by various customers of the services rather than measured. While this is far more subjective, obtaining ratings from a variety of sources may provide some viable information. Pilot test results will help to determine the efficacy of using this approach.

Publication of the final report of the study is planned for late 1996.

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MANAGING THE LEGAL LIABILITIES AND RISKS INHERENT IN THE DELIVERY OF ASSISTIVE AND REHABILITATION TECHNOLOGY SERVICES AND DEVICES

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ABSTRACT

This paper describes strategies for effectively managing the legal liabilities and risks associated with the delivery of assistive and rehabilitation technology (AT/RT) services and devices. Because services and products are delivered to consumers, assistive technology practitioners and rehabilitation technology suppliers assume significant legal responsibility for their actions, to the extent that the consumer has a legally enforceable right to AT/RT services that meet or exceed professional standards and to AT/RT products that will not cause injury under normal use (1). Professional and product liability issues are presented in relation to the delivery of AT/RT services and devices, followed by a discussion of eleven strategies that, when followed, reduce the risk of injury to the consumer or others, thereby containing the legal risk associated with the delivery of AT/RT services and devices.

BACKGROUND

Assistive technology practitioners (ATP's) and rehabilitation technology suppliers (RTS's) provide assistive and rehabilitation technology (AT/RT) services and devices to consumers. These services and devices are extremely broad in scope and complexity, depending upon consumer need and service provider capabilities. Yet, in all cases, regardless of breadth or depth, the ATP or RTS is legally responsible, or liable, for the services and, to a variable degree, for the products he or she provides. Most unfortunately, the services and products provided by ATP's and RTS's can cause injury and death (2). As a result, the ATP or RTS assumes significant liability for their actions.

The liability shouldered by ATP's and RTS's falls into two categories, professional liability and products liability. Professional liability is synonymous with malpractice, which has been defined by the courts as unprofessional conduct in the handling of professional matters, resulting from ignorance, carelessness, want of professional skill, or disregard of established rules (3). Products liability "deals with the liability of manufacturers, distributors, retailers, and others for damage caused by defects or dangers in their products, whether the damage be suffered by those with whom they deal or by others" (1). In a broad sense, products liability relates to liability arising from the use of a product (1).

While ATP's and RTS's might think that they are free of products liability when they simply provide a commercial product, that may not necessarily be the case. Some courts consider negligence within products liability claims. In these instances, a seller or supplier is subject to liability for negligence relating to his or her function in the distribution of a product (1). For example, a supplier of a product is under a duty to provide adequate directions or instructions for the proper use of a product, when required by law or circumstances; failure to do so constitutes negligence (1).

Stricter products liability standards apply when ATP's and RTS's combine AT/RT components to form systems, modify commercial products, or manufacture custom products for consumers. In cases where components are combined, the courts are hesitant to hold the manufacturer of the components responsible under the strict liability doctrine. In fact, the courts often rule that the "manufacturers cannot be responsible for a combination which they did not recommend and which they had no way of guarding against at the manufacturing stage" (1). When ATP's or RTS's modify or manufacture products, they are fully liable under products liability law. This holds true even for simple modifications, such as the trimming of a commercial wheelchair cushion to fit a particular wheelchair.

While the liability risks are quite high for ATP's and RTS's, it can be said that too little attention is paid to this issue. A review of the RESNA Proceedings from 1982 - 1995 yielded no article specifically addressing liability issues. Ellingson briefly touched on the issue in 1983 (4), as did Axelson and Chesney in 1995 (2), but the issue of injury, liability, and risk management has not been addressed beyond that. Nor has is been addressed in the RESNA publication Assistive Technology. In the final analysis, though, ATP's and RTS's bear significant risk of liability in the provision of AT/RT services and products.

STATEMENT OF THE PROBLEM

The problem under consideration relates to risk and the effective management of risk. First, and most tragic, is the risk placed upon the consumer or general public, that being the risk of unnecessary injury or death. The second risk is the legal and financial liability borne by the ATP or RTS as a consequence of the injury to the consumer. If the ATP's or RTS's do not take specific steps to reduce the risk of injury to the consumer or others, they place themselves at extremely high risk for a liability judgement made against them. Similarly, ATP's or RTS's might take the proper steps to reduce the risk of injury, but neglect certain procedures for effectively managing their liability. In these cases, even though a consumer's injury might not be the result of malpractice or products liability, the ATP or RTS risks being unable to adequately prove this. Consequently, they remain at high risk for a liability judgement against them.

As can be seen, the risks are high. But, to a large extent, they are manageable. In the section that follows, strategies for effectively managing legal liabilities and risks are presented.

APPROACH

The approach to effectively managing liability can be separated into distinct strategies. Such a separation assists the ATP and RTS in assessing their current risk management practices and incorporating neglected procedures into their overall service delivery process. Eleven strategies are presented below.

1. Stay within the boundaries of your expertise or competence

ATP's or RTS's should not stray beyond the limits of their expertise or competence. Doing so risks immediate malpractice repercussions. The dilemma relates to one's perception of competence. It is not the RTS's or ATP's perception of competence, but is the court's, that dictates liability. Is an ATP or an RTS who has no formal training in structural analysis liable for drilling a hole in the frame of a wheelchair, which might result in structural failure and consumer injury? Legal rulings suggest he or she is liable.

2. Acquire expert oversight and/or consultation

If an RTS or ATP is at risk of straying beyond their boundary of expertise, they should seek the services of an expert for supervision or consultation. Doing so greatly reduces the risk of liability for the service provider, as long as the relationship is formal in nature and is properly documented.

3. Seek out risk management experts for guidance

The benefits of consulting a risk management specialist cannot be overstated. The specialist can offer suggestions to improve one's overall risk management practices, as well as serving as a consultant prior to accepting specific cases that may be deemed risky. The specialist can offer additional support unique to particularly risky cases.

4. Maintain contact notes with every case

Document each contact made with the consumer and the consumer's primary care providers. Documentation should list all participants of the contact, as well as detail communication, actions and interactions, findings, and unusual occurrences. The note should be signed and dated for each contact made, whether it be direct contact, telephone contact, or contact through an intermediary.

5. Maintain a detailed record of all services and products delivered

This record should detail the what, why, when, where, how and who of services and products. Comprehensive records detailing device selection, modification, and customization need to be included. Photographs are essential to demonstrate the products and their alterations, as well as their proper fit and function. How can the ATP or RTS prove that the product has been altered by another party, if they lack documentation detailing the product's original form? "Where the trier of the facts reasonably can find that the product is unchanged from the condition it was in when sold and the unusual behavior of the product is not due to any conduct on the part of the plaintiff or anyone else who has a connection with the product, logic dictates that it is a distinct possibility that there is some defect in the product" (1).

6. Fully document risks

Fully document all risks associated with a case. Detail the risks or problems that existed prior to intervention, the prior attempts to alleviate the risks or problems, the reason for the request of the service or product, and any new risks posed by the new service or product being provided. If it can be demonstrated that the consumer is at greater risk resultant to no service or product than with a service or product containing inherent risks, the court will often rule in favor of the intervention.

7. Provide training on proper use, care, maintenance, and evaluation of devices

As stated earlier, suppliers of products have a duty to provide adequate directions or instructions for the proper use of a product. Failure to due so may constitute negligence. In the best of worlds, the instructions should be provided to the consumer in a hard copy form.

8. Follow up on services and products

Follow up with the consumer and the primary care providers demonstrates an effort to ensure that the services and/or products are effective and continue to safely meet the consumer's needs. Follow up also facilitates intervention in the event that problems or dangers arise.

9. Have consumers return modified or customized equipment when they no longer use it.

If a person other than the primary consumer gains possession of a modified or customized product and is injured by its use, the supplier may be found liable for damages. To avoid this problem, the supplier should make the return of the product a condition of the terms of service. This absolves the supplier of liability in the event that the primary consumer then chooses not to return the product.

10. Use of a liability waiver.

Liability waivers should not be relied upon. They are rarely, if ever, enforceable. A disclaimer prepared after consultation with legal counsel may be utilized.

11. Do use an informed consent document.

The informed consent document is not a waiver of claims. Rather, it serves as additional documentation of the appropriateness of the service and/or product. The document should contain the details described in strategies 2,5,6,7,and 9. Both the service provider and the consumer should sign and retain copies of document.

IMPLICATIONS

The implications are clear. Incorporation of a risk management strategy into the AT/RT delivery process significantly reduces the risk of injuring consumers and members of the general public. Consequently, the risk of malpractice and products liability claims are effectively managed. On the other hand, failure to incorporate risk management strategies into the delivery process leads to potentially devastating and life threatening dangers.

DISCUSSION

As can be seen, injury prevention, liability, and risk management are significant issues affecting RTS's and ATP's as they deliver AT/RT services and products. As a professional society of ATP's and RTS's, we don't hear a great deal about court rulings related to AT/RT liability. Are we lucky, so far? Are we that effective at managing our risk? Is a significant accident or injury waiting to happen?

RESNA is beginning to address this issue through its QA initiative. But ATP's and RTS's cannot rely on RESNA to be the sole provider of risk management. `Rather, it is the professional's and the employer's responsibility to take tangible steps to prevent consumer injuries, thereby effectively managing liability and risk.

While this paper does not pretend to have all of the answers to these issues, it is hoped that it can serve as a catalyst for thought and consideration of a comprehensive strategy for managing liability and risk, and most importantly, for reducing the unnecessary injuries brought about by AT/RT intervention.

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QUALITY MANAGEMENT CERTIFICATION TO ISO 9001: EXPERIENCES OF A REHABILITATION ENGINEERING SERVICE

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ABSTRACT

Regency Park Rehabilitation Engineering was certified in October 1995 as complying with the requirements of the ISO 9001 Quality Systems Standard. In our view, the Standard has much to offer the disability field, in terms of clarifying contractual obligations and asserting effective management practices that focus on customer service, continuous improvement, teamwork, measurement and data. This paper describes our objectives in obtaining certification, the documentation that needed to be written, the 20 elements of contractual situations that needed to be addressed, and our impressions of what we have gained. During 1996, we will move on to address Total Quality Management, and by 1998 the rest of our organisation will also achieve certification to ISO 9001.

BACKGROUND

International Standards for Quality Assurance are gaining acceptance in a wide variety of industries as a means of demonstrating confidence that an organisation will deliver what it claims to deliver.

To our knowledge, the ISO 9000 series of Quality Standards (1) has not yet been widely used in the disability field. The introduction of ISO 9000 Quality Systems to a part of the National Health Service wheelchair prescription in the U.K., with particular emphasis on the design of the clinical documentation for the referral, assessment and prescription parts of the process, appears to have been very successful (2). We have previously reported on our experiences in the period leading up to certification (3).

OBJECTIVE

Our objective was to implement AS/NZS ISO 9001: 1994. This terminology means a combined Australian and New Zealand Standard, published in 1994, being a re-badging of ISO 9001. The reasons for taking on this onerous task were:

1. To give ourselves an external assessment of our management system at a time of change due to an exchange of services with a sister organisation. In 1993, we exchanged services with Spastic Centres of South Australia, taking our Rehabilitation Engineering staff numbers from 25 to 45 (staff numbers are now settling back to 35 as one unit is re-auspiced, maintaining its QA Certification).
2. Government funding bodies have indicated that they will favour suppliers who have Quality Assurance Certification, and we decided to meet their wishes before they became firm requirements.
3. Being one of the first in the disability field to be certified enhances our reputation as a centre of excellence.

METHOD

We found that by far the most intellectually difficult part of establishing a Quality System was to interpret the broad, sweeping statements in the Standard to the specific needs of a workplace, which in our case included customised orthotics, footwear and wheelchairs, importing electronic devices, a testing laboratory, therapy and assessments, and fundraising. We found that preparing a Policy Manual was fairly easy because it only needed to be quite general.

The Procedure Manual was the most difficult part. It contains the following 20 elements, and we found the following questions to be useful prompts:

1. Management Responsibility
   Have all staff seen and understood their responsibilities in the QA Procedure Manual?
   Have all staff used a non-conformance report to improve our service?
2. Quality System
   Do all staff know where the Quality documents are kept?
3. Contract Review
   Are you clearly defining all customer requirements and how?
   Are you using a contract review stamp for every new job?
4. Design Control
   Is a design brief form used to begin the design process?
   Do new designs go through a formal specification, verification and validation procedure?
5. Document and Data Control
   Are our procedures and work instructions controlled to make sure you have the latest version?
6. Purchasing
   Is your schedule of suppliers kept up-to-date with any supplier problems?
   Are there clear limits on who can authorise what amount of expenditure?
7. Control of Customer Supplied Product
   How would you know if you had damaged a client's equipment?
8. Product Identification and Traceability
   How do you label or tag products in order to identify and trace them?
9. Process Control
   Are the important parts of your work procedures documented?
10. Inspection and Test
    Is your work checked appropriately?
11. Control of Inspection Equipment
    Is equipment or software that is used to measure products or client performance checked?
12. Inspection and Test Status
    How would you know whether a particular job had been checked?
13. Control of Non-Conforming Product
    How do you prevent a sub-standard product from being issued?
14. Corrective and Preventative Action
    How do you correct a mistake?
    How do you prevent it from recurring?
15. Handling, Storage, Packing and Delivery
    How do you look after product so that it reaches the client in good order?
16. Control of Quality Records
    How are quality records preserved?
17. Internal Quality Audits
    How do you schedule them and keep the records?
18. Training
    Are staff educated, trained and experienced in the work they do?
    Where are training records kept?
19. Servicing
    Does not apply to us.
20. Statistical Techniques
    If you sample, how do you establish that the sample represents the whole population?

Procedures that are important to the quality of the product or service you provide, but which relate to only a part of your organisation, need to be documented in Work Instructions, which are referenced in the appropriate element of the Procedure Manual.

RESULTS

Before inviting the certification body to audit your system, you are required to conduct your own internal audit. It then becomes clear that ISO 9001 is really an elaborate checklist using the questions above and many more besides. The two questions that auditors have to ask are:

- Do your written procedures say that you comply with the 20 elements of ISO 9001?

- Can you prove by written records that you follow your own procedures?

At both our internal audit and our external audit, we found areas that needed improvement. We passed the external audit at the first attempt.

There have been several positive results for us in having achieved ISO 9001 certification:

1. The Standard directs our minds towards the many aspects involved in the contractual obligation known as customer service.

2. It sets up a clear system for achieving continuous improvement: staff are expected to raise non-conformance reports when something goes wrong, and management is expected to ensure that that incident is corrected and that recurrences are prevented

3. Management teamwork was strengthened through the need to achieve consistent interpretations of the Standard and establish systems that were compatible between departments.

4. Objective measurement of performance and a statement of goals are encouraged. Trying to meet our own performance objectives required changes which caused stress in the short term in some areas of our operation. In the medium term, we expect to achieve better customer service in those areas.

5. A procedure manual now exists which is very specific and which assists in the induction of new staff.

6. We are using supplier schedule entries to feed back any difficulties to suppliers, with the aim of improving customer service.

7. Our design process has been made more formal, involving more teamwork, and we keep better records of progress on projects.

The major difficulties are in interpreting ISO 9001 to your own organisation, and in making the time available to document your current processes and to improve them where necessary to meet the requirements of the Standard. We are very glad to have all that behind us.

DISCUSSION

Quality Assurance is:

- How we organise, supervise, manage, and check our work
- How we meet or exceed customer expectations, and
- How we avoid the common mistakes in contractual situations.

We have found it a useful exercise, and it will be a good discipline for us to have an external review team come in and check our management system against an elaborate checklist every 12 months, in addition to the internal audits we are required to do on the alternate 6 months.

We have also laid the foundations for moving on to Total Quality Management for continuous improvement, in which we will have to continually upgrade the extent to which we meet each of these basic measures:

1. Quality is defined in terms of customer perceptions.
2. The system is enhanced by improving processes within the system.
3. Suppliers and contractors are treated as partners in the system.
4. Statistical thinking and methods are used to manage and reduce variation.
5. All people are creatively involved in continuous improvement of the system.
6. Continuous improvement activities are integrated with the strategic and annual planning cycle.
7. Continuous improvement is led, managed and supported at all levels in the organisation.

Regency Park Rehabilitation Engineering is a division of the Crippled Children's Association of SA Inc, and the remainder of that organisation intends to achieve Quality Assurance Certification by 1998.

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THE ROLE OF DEVICE LOAN IN PROCUREMENT OF APPROPRIATE ASSISTIVE TECHNOLOGY FOR VOCATIONAL REHABILITATION

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Abstract:

A rehabilitation agency with an emphasis on employment for persons with disabilities has been offering device loan opportunity for five years. Ten percent of the individuals borrowing equipment have vocationally related needs. The effect of borrowing and using equipment prior to the commitment of funds is investigated. General data and case studies are presented. This model is extremely beneficial for Rehabilitation Services who, in an environment of reduced funding, must consider the utilization of assistive technology for their clients.

BACKGROUND

Device Loan Resource

The device loan resource, which is operated by a rehabilitation engineering center, is supported by state funds. Over 700 items are available to be borrowed by persons with disabilities. The eligibility requirement is to be a resident of the state. The standard loan period is one month; this can be extended by agreement. Criteria for extension are the duration of a temporary need or a training program.

As seen in Table 1, during the three-year period, one tenth of the loan incidents related to vocational needs of the borrower. Of these instances, over half (23 of 43) were referred by a counselor of Rehabilitation Services. Items loaned were devices to enable performance of activities of daily living as well as occupational tasks.

Service Year	Total Number of Borrowers	Number With Vocational Need
1993	131	11
1994	127	13
1995	172	19
TOTAL	430	43

Table 1. Borrowers with Vocational Needs

Of those who borrowed devices, 20 of the 43 instances were for an individual who was employed. An employee may acquire a limitation in a vocationally required function, from trauma or damage by repetitive motion, or a new task may be added to the occupational requirements. The referral may originate from the employer or employee. When significant limitation exists, the employee may be referred to Rehabilitation Services. In the latter case, the counselor is the party to make the referral.

Of the 43 cases cited, 36 (83.7%) had a limitation of hand function. Twenty-five of these persons were limited in their ability to perform computer keyboard input required in their job. Seven individuals required adapted access to doors in the workplace. This was typically solved by using a simple add-on lever of rubber or metal. The cost of such an adaptation is less than $10. Thirteen required assistive devices to perform activities of daily living in their homes to get ready for work.

VOCATIONAL ASSISTIVE TECHNOLOGY CASE STUDIES

Individual With Hand Injury

A high school teacher was referred for consultation by his vice principal. This individual had been injured in an industrial accident. A major portion of each hand had been severed in a metal shear. Both thumbs were intact, only a small portion of the fingers of the left hand and a part of the index finger on the right, dominant, hand remained.

It was impossible for the individual to use a standard computer keyboard. His writing was laborious. The job-related task that required assistance was keyboard input on a computer. This would enable him to prepare handouts, exercises and tests for his classes.

The Intellitools membrane keyboard was recommended and loaned. This device is transparent to computer software and is easily installed for use. These characteristics were desirable since the teacher would need to use computers in different locations in the school.

After the initial loan period, the user said that the device was very useful. A meeting was arranged with the vice principal, the teacher, and the device librarian. The teacher described his experience using the keyboard. The device librarian presented product information, including cost and source of the device. During the meeting, the vice principal said she would authorize purchase of the device from a fund set aside for ADA compliance. The cost was just over $400. The loan period was extended to allow continued use of the keyboard until the authorized device was received. The outcome of the loan opportunity was that the employer was assisted to purchase an assistive device with the confidence that it would enable the employee to perform a required job task.

Individual With Carpal Tunnel Syndrome

An individual with an office job who had two surgeries for carpal tunnel syndrome reported pain when performing computer keyboard input. A pair of floating forearm supports, Ergo Rests, was loaned. This product, manufactured in Finland, was procured from the Adaptive Division of Willow Pond Tools. The user said that these devices were effective in allowing her to perform computer input without pain.

The individual subsequently obtained employment with a different company. At her request, the device librarian sent a letter to the new employer describing the forearm rests. The brand name, source, and cost were reported as well as the user's experience with the devices. The new employer elected to purchase the devices at a cost of approximately $350.

Individual With Fibromyalgia

A client of Rehabilitation Services was referred to the device loan resource to identify assistive equipment which could alleviate the various symptoms of fibromyalgia. The client's plan included further university study to allow her to function as a supervising nurse and devices to make homemaking tasks easier. The initial contact was made a month before the semester ended.

The immediate concern was to produce handwritten and computer reports. The client said that she could neither type nor write more than one-half page at a time without severe pain in the wrists, elbows, and shoulders.

The client chose to borrow a pair of forearm rests to be used with her computer and several items to make it easier for her to perform activities of daily living. The items were returned at the close of the semester.

The client reported that she had produced 100 pages of computer-generated material in the final week of the semester without experiencing pain. She also reported that she had been free of chronic headache during that time. Her opinion was that relieving stress on her hands, arms and shoulders had made her more relaxed, thus eliminating the cause of the headaches. The client was extremely pleased.

In six subsequent visits to the device library, she borrowed 40 devices. Of the 40 devices, 25 related to activities of daily living and 15 related to specific vocational or training needs.

The client submitted a prioritized list of items to her counselor. Her first choice was the forearm rests, which expended over half of the $600 which had been authorized. Fifteen additional items were purchased of which 10 related to vocational needs.

The client continues to borrow items from the device library. She has purchased three additional items herself. She has developed a list of items to purchase as personal funds are available.

CONCLUSION

The utility of experimental use of adaptive equipment appears to have been demonstrated in the cases presented. The effectiveness of device loan in vocational as well as other areas will continue to be documented by the device loan center.

RECOMMENDATION

The agency sponsoring the device loan resource is an integral part of the "Tech Act" endeavor in its state. Tech act sites are likely facilities for device loan banks. Another mode enabling persons to experiment with the use of specific assistive equipment would be augmented opportunities for rental or return of purchased equipment from suppliers of durable medical equipment. A statewide database of equipment that is available for purchase, rental, or loan would be useful.

Sources of Cited Devices

Intellitools, Inc.
55 Leveroni Court, Suite 9
Novato, CA 94949
(510) 528-0670

Willow Pond Tools
Adaptive Division
P. O. Box 544
435 Deerpath Lane
Pembroke, NH 03275
(603) 4585-2321

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THE ASSISTIVE TECHNOLOGY - CHICAGO PROJECT PRELIMINARY COST / BENEFIT RESULTS

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ABSTRACT

While the potential benefit of assistive technology to a specific individual with a disability is a powerful argument for its acquisition, additional information is sometimes needed for a third-party payor to provide prior approval. The "Assistive Technology - Chicago" Project enabled Evaluations to be provided to 150 clients receiving city-provided Meals-on-Wheels or Homemaker services. An analysis of the first 50 individuals receiving equipment indicates that 90% were able to reduce or eliminate their need for services, with a return-on-investment of approximately 20:1.

BACKGROUND

Assistive technology service providers routinely ask third-party payors to make an investment in equipment to enable individuals with disabilities to maximize their independence. The concise, accurate description of the impact of that equipment on the life of the individual is the most important information that a service provider can produce, and is usually the result of significant time and effort.

Additional information is sometimes included to make the third-party payor more confident about the investment in the assistive technology equipment. One such piece of information is the economic impact of the equipment implementation.

The Assistive Technology - Chicago Project was designed to study the cost - benefit of assistive technology as it is used by individuals with disabilities in their homes. Specifically, individuals with disabilities receiving city-provided Meals-on-Wheels or Homemaker services received Evaluations to determine if assistive technology could enable them to perform all the activities involved in meal preparation and homemaking.

City residents with disabilities calling the city to inquire as to the availability of the Meals-on-Wheels or Homemaker services are referred to one of two community agencies based on the location of their home. A case manager from the community agency then visits the home to document the need for the service. The case manager also determines the appropriateness for concurrent referral for assistive technology services.

RESEARCH QUESTION

The Project lends itself to the examination of issues that include the following:

- types of equipment provided
- cost of equipment per client
- number of clients able to reduce need for services
- service savings
- time for equipment to pay for itself
- return-on-investment

Issues involving the costs of city-provided services were examined using the city-provided information on the cost of provision of the Meals-on-Wheels (cost per day of delivered meals) and Homemaker services (cost per hour).

METHOD

Services were provided through clinicians with backgrounds in occupational therapy and rehabilitation engineering. Two clinicians were sent on each appointment, to combine the expertise of clinicians and for safety.

All Assistive Technology - Chicago Project services were provided through mobile units which enabled Evaluation and Fabrication services to take place in the community (Figure 1). This was an essential part of the Project, as the need for city-provided services was the result of the client's abilities and the environment in which those abilities are utilized (1).

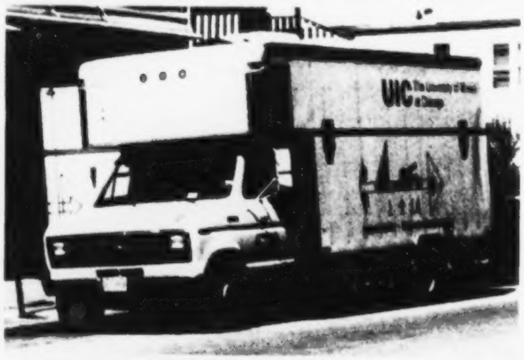

Figure 1.

Evaluations were performed that analyzed the individual activities within meal preparation and homemaking, so that instances where the client's abilities did not match the specific task needing to be carried out could be identified. The clinicians and client discussed the issues that presented themselves, and what options existed. Assistive technology equipment was identified that would enable the client to work with their abilities to perform the identified task. Most often, the Evaluation team had the piece of equipment to try out during the session. Reports were then generated to the city for prior approval of the equipment acquisition.

At the Implementation visit, clinicians provided training regarding the use and care for the assistive technology, and documented the ability of the client to perform the given activity. The community agency case manager then revisited the client to re-assess the need for city-provided services after the equipment had been issued.

RESULTS

Of the 154 clients receiving Evaluations, equipment was considered appropriate for 104. Of these 104 clients, prior approval was received for the acquisition of equipment for 65. For some clients, equipment requests were denied or referral was made to other agencies for funding consideration.

The type of equipment issued to the clients varied greatly. In all cases, commercially-available equipment was considered first, modified equipment was considered next, and custom-designed equipment utilized as a third option.

For clients receiving Meals-on Wheels, equipment issued included food storage containers with adaptive lids, storage shelving and carousals to locate food and kitchen equipment within an individual's functional range of movement, reachers, adapted can openers, adapted bottle and jar openers (Figure 2), adaptive knives, cutting boards, microwave ovens with tactile borders and programmable cooking capabilities, extra-long oven mitts, stools, plate guards, and adaptive utensils.

Figure 2.

For clients receiving Homemaker services, equipment issued included long-handle brooms and dust pans (Figure 3), carpet sweepers, power-drive vacuum cleaners, adapted mops, and adapted irons. Some clients receiving Homemaker services also received accessibility equipment for the bathroom area, as some clients would bathe while their Homemaker was working in the home in case they fell and needed assistance. This group of equipment included bathtub transfer benches, grab bars, hand-held showers, bath mats, and raised toilet seats.

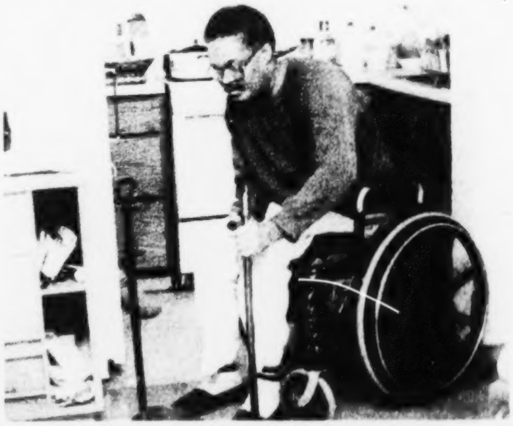

Figure 3.

An analysis was made of the impact of the assistive technology for the first 50 clients receiving equipment. Of these 50 clients, 25 received equipment related to meal preparation. Of these 25, a total of 21 were able to reduce or eliminate their need for the delivered meals. Cost of the equipment ranged from $26.09 to $923.84, with the average being $234.85.

Of the 50 clients, 31 received equipment related to homemaking. Of these 31, a total of 24 were able to reduce or eliminate their need for the outside homemaker. Cost of the equipment here ranged from $58.50 to $729.20, with the average being 345.73.

Table 1 shows the results for the group of 50 clients. A total of 45 (90%) were able to reduce or eliminate their need for city-provided Meals-on-Wheels and / or Homemaker services.

Table 1.

Clients receiving equipment	50
Service Level after Implementation	
Reduced	45
Increased	2
Unchanged	3
Equipment cost	
Range	$26.09 - $923.84
Average	$324.27
Time required to cover cost of Assistive Technology	
Range	0.90 weeks - 66.76 weeks
Average	10.31 weeks

When determining the return-on-investment for the city, the cost of the service savings (calculated from the year of service to the year that the client would turn 60 years of age and be served by another city agency) was compared to the cost of the assistive technology equipment. For the 45 clients that had been able to reduce or eliminate the need for services, the city would realize a total savings of $867,531, and the return-on-investment in assistive technology would be 20.58:1.

DISCUSSION

The preliminary results of the Project indicate that when service providers recommended equipment, and were able to implement that equipment, there was a 90% likelihood for assistive technology equipment to not only increase an individual's level of independence, but to save third-party payor funding.

This Project only addresses the issues of assistive technology used in the home environment, dealing specifically with the issues of meal preparation and homemaking. A cost / benefit analysis of the application of other types of assistive technology would involve the quantification of other types of cost factors, such as pressure sore or scoliosis treatment, unemployment vs. employment costs, and personal assistance. Also, the total savings for the city, and resulting return-on-investment, would be influenced by client longevity and changes in functional abilities.

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A COMPARISON OF INPATIENT AND OUTPATIENT REHABILITATION ENGINEERING SERVICES IN AN ACUTE REHABILITATION SETTING

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ABSTRACT

A comparison is made of rehabilitation engineering services provided to inpatient and outpatients in an acute rehabilitation setting. Data is collected from inpatient and outpatient records on the types of patients and the amounts and types of services received. Implications to the model of rehabilitation engineering in the acute rehabilitation setting are discussed.

BACKGROUND

Rehabilitation engineering services are provided in a number of medical centers as part of an acute, comprehensive rehabilitation program. It has been postulated that early intervention in such a setting may lead to improved patient independence and efficiency of service delivery (1). However, the proportion of medical centers which employ rehabilitation engineers remains small (2). In order to justify the existence of rehabilitation engineers in this setting, it is critical to provide evidence of improved patient outcomes as a result of service in the acute setting. As an underlying component, the characteristics of service delivery should be helpful in determining why this particular model is or is not successful. This information should then be useful in justification of service delivery in the acute-care environment, and would also provide valuable feedback to the service providers.

The rehabilitation engineering program (REP) analyzed in this paper is part of a university-based regional medical center. It provides services to patients throughout their hospital stay and may continue to follow them after discharge. Clients are also referred as outpatients. A large proportion of service is geared towards environmental control, computer access (including both interface and computer literacy issues), and augmentative and alternative communications. A wheelchair mobility and seating service at an offsite location sees clients primarily on an outpatient basis. Detailed descriptions of these programs can be found in previous papers (1,3).

OBJECTIVE

The objective of this paper is to quantitatively compare certain aspects of the service provided to a group of inpatients and a group of outpatients at an acute rehabilitation center. The two groups will represent the acute rehabilitation model and the outpatient rehabilitation model, respectively. Comparison of the two groups will hopefully improve our understanding of the manner in which an acute-care rehabilitation engineering program differs from other models. Although patient outcomes were not measured, quantitative data on the service delivery of our program can provide insights into strengths and weaknesses of the program and validate (or invalidate) previous assumptions about the service delivery model. Specific questions which will be considered are: is this model effective in providing access to assistive technology services? Does this lead to increased evaluation and training time?

METHODS

Data was collected from all inpatients and outpatients who met two criteria: (a) equipment had been ordered for the patient within the last two years; and (b) the patient had had their initial contact with the rehabilitation engineering program within the last three years. Patients for whom no equipment had been ordered were excluded in order to obtain a better match of services provided to the inpatient and outpatient groups. This excluded a large number of inpatients who were provided with access to nurse-call controls and/or varying levels of orientation and evaluation as part of their inpatient service. Patients who had been initially contacted more than three years ago were also excluded to reduce the number of patients who had had "re-evaluations" and thus would have inflated statistics. Patients from the off-site seating service were not included in this study.

All data was collected retrospectively from patient charts. Data was collected from 45 patients, including 5 with incomplete records (one or more data values not available). The following data was collected:

- age of patient
- type of disability
- source of initial referral (inpatient or outpatient)
- length of initial inpatient rehabilitation (if the disability was recently incurred)
- amount of time spent in evaluation or in training as an inpatient for the various types of services
- amount of time spent on environmental control for use during a hospital stay
- amount of time spent in evaluation or training as an outpatient
- cost of equipment
- type of equipment

Amount of time spent on environmental control for use during a hospital stay indicates time spent in providing access to the nurse-call, TV, hospital bed, and other devices. This was separated from inpatient ECU evaluation because inpatient evaluations focus on the patient's needs following discharge as opposed to the patient's needs while in the hospital.

RESULTS

Tables 1 and 2 summarize the ages and types of disabilities seen for all patients included in the study. Thirty-one of the patients were initially contacted during an inpatient hospital visit, while twelve patients were initially contacted as outpatients.

Table 1. Summary of Patient Ages

Average Age: 40 yrs.

Age 1-20	4	Age 41-60	17
Age 21-40	17	Age 60+	4

Table 2. Types of Disabilities Seen

	Initial Contact as:	
DISABILITY	Inpatient	Outpatient
Spinal Cord Injury	21	2
Traumatic Brain Injury	1	4
Multiple Sclerosis	0	2
Cerebral Palsy	1	2
Stroke	0	1
Blindness	1	0
Others	7	2

Tables 3-5 summarize the service-delivery statistics for AAC, environmental controls, and computer access. Only patients for whom equipment had been ordered relevant to the type of service are included. For example, a patient who had an AAC evaluation but had no AAC equipment would not be included.

In the tables, "Eval Time" is the average time per patient spent on evaluation and/or training. "In-hospital ECU Time" is the average time spent on evaluating and training a patient for environmental control to use while in the hospital. "Equip Cost" is the hardware cost per environmental control system. "Length of Rehab Visit" is the time from admission to the rehabilitation unit to the time of discharge.

In general, equipment was provided on an outpatient basis, even for those who had been evaluated as inpatients. The exception to this is in environmental controls. A significant number of patients were provided with equipment from the REP's stock during their hospital stay. For the other services, patients had to wait for insurance approval and shipping time. One patient received ECU equipment as both an inpatient and an outpatient.

Table 3. Summary of AAC Service

	Inpatient	**Outpatient**
# Patients	1	5
Disability:		
CP	0	2
TBI	0	2
ALS	0	1
Other	1	0
Eval Time	5 hrs	4.25 hrs

Table 4. Summary of Computer Access Service

	Inpatient	**Outpatient**
# Patients	8	5
Disability:		
SCI	6	0
TBI	1	2
Stroke	0	1
Blindness	1	0
Eval Time	28.5 hrs	7.5 hrs

Table 5. Summary of Environmental Control Service

	Inpatient		**Outpatie**
	IP Equip*	OP Equip**	
# Patients	14	12	3
Disability:			
SCI	8	11	0
TBI	0	0	1
MS	0	0	2
CP	0	1	0
Other	5	0	0
Eval Time	1.3 hrs	2.7 hrs	1.5 hrs
In-hospital ECU Time	2 hrs	2.3 hrs	N/A
Equip Cost	$110	$1650	$1100
Length of Rehab Visit	2.4 mo.	3.6 mo.	N/A

* Inpatients who were provided with ECU equipment during their inpatient (IP) stay

** Inpatients who were provided with ECU equipment as outpatient after discharge

DISCUSSION

The first issue to be addressed is to determine the relative frequency of service provision between the inpatient and outpatient settings. This will be discussed separately for each of the three assistive technology service areas.

For AAC, five out of six patients who received equipment were referred as outpatients. The acute-service model was not a critical component

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in providing access to services in this case. This may be because the majority of AAC users have long-standing disabilities which would not be appropriate for treatment in an acute rehabilitation setting.

For computer access, the number of patients who received equipment is fairly evenly distributed between inpatient and outpatient referrals. This implies that both the inpatient and outpatient models were important components of service provision in this area. However, whether access to services provided in the inpatient setting can effectively be replaced in the outpatient setting remains an unanswered question.

The level of access to services for environmental controls was high in the acute setting. Twenty-six of twenty-nine patients who received environmental controls equipment were initially referred as inpatients. The provision of simple environmental control for nurse-call and TV controls as a standard service may be largely responsible for this. Another factor may be that the time required for evaluation is relatively short, and in many cases some equipment was provided from REP stock. Finally, the need for environmental controls may be most apparent to patients with newly acquired disabilities, while outpatients may have become accustomed to doing without.

The next issue is whether the acute-service model results in increased evaluation and training times? The data here for AAC is inconclusive, since only one patient received AAC services as an inpatient. The data for environmental controls is also inconclusive; only three outpatients received equipment, and for one of these, the evaluation/training times were not available.

However, the evaluation and training time for computer access is much greater for inpatients than for outpatients (about four times greater). As an acute-rehabilitation service, the REP is able to see clients several times a week to allow to them to try many different types of computer systems and to give in-depth training on a particular software package. This type of evaluation and training would be difficult to arrange in an outpatient facility.

No measures were taken to see if this increased training time resulted in improved outcomes. It could be expected that increased training time will lead to more efficient and frequent equipment use. In addition to this, training may be therapeutic. It can increase self-esteem and provide recreational release while in the hospital. It may also stimulate the patient to pursue new interests and may even lead to career options. On the other hand, patients in rehabilitation may be adjusting to a new disability and may not have developed clear goals beyond discharge. Their functional status may be changing during the hospital stay, requiring changing methods of computer use. The effectiveness of increased training may be reduced in these situations.

A significant statistic is that fact that 20 of the 31 inpatient-contacts had spinal-cord injuries. The medical center in which the REP is based contains a Model Spinal Cord Injury Program. This influences the types of services that are provided. This is particularly obvious in computer access and environmental controls.

CONCLUSION

Only a small number of the factors that influence the effectiveness of assistive technology provision have been examined in this paper. However, the data collected does support the idea that an acute-service model can lead to increased access to services for environmental controls and increased evaluation and training time for computer access.

To properly justify the placement of rehabilitation engineering services within an acute rehabilitation setting, much more work is needed. Measures of patient outcomes, in terms of functional, economic, and emotional benefits, will be at the heart of this process.

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TECHNICAL CONSIDERATIONS FOR INTEGRATING VENTILATORS WITH MANUAL WHEELCHAIRS

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ABSTRACT

The quality of life of those individuals who are ventilator dependent will be greatly improved if their respiratory support equipment can be incorporated onto their wheelchairs. However, there exists limited space underneath the wheelchair which can be used, and the weight distribution of these equipment should not alter the stability of the wheelchair, as well as causing obstruction to the body. Depending on the requirement of each individual, the design considerations for integrating ventilators with wheelchairs will be slightly different. This paper describes the overall considerations involved in mounting respiratory support equipment onto manual wheelchairs, and discuss three different cases that were encountered in our recent practice.

BACKGROUND

Individuals suffering from progressive neuromuscular diseases, high level spinal cord injuries and other respiratory diseases will require tracheotomies and ventilators support to sustain their life. Traditionally, these patients are usually long term hospitalized and bedridden. Modern technology has enabled those ventilator-dependent patients to become ambulatory, so that they can access and reintegrate themselves back to the community. In Hong Kong, there seems to be an increasing demand on fitting portable ventilators onto wheelchairs for patients who are in need. Three separate cases have been encountered by our Center within the past 18 months. These included one congenital spinal muscular atrophy child, one teenager with cervical spinal fracture and one elderly suffering from respiratory disease.

PROBLEM

Ideally, the decision for integrating a mechanical ventilator with a wheelchair should be well considered before any equipment is purchased. This would help to ensure an optimal integration, and often, any necessary fittings and modifications can be installed by the wheelchair manufacturer. In reality, ventilators are often prescribed during the emergency phase, where patient's mobility is not a principal concern. However, as rehabilitation progresses, wheelchairs will be prescribed to improve the quality of life. It is then that rehabilitation engineers are being called upon to face the challenge of designing a mounting system that can safely be attached the complete ventilator unit, but without alternating the structure of the wheelchair. This often poses additional difficulties and creates unnecessary constraints on the design, particularly in cases where wheelchairs are purchased from a catalogue and very limited information is available.

DESIGN CONSIDERATIONS

The portable mechanical ventilator unit comprises of the ventilator, an external battery source and the necessary tubing. In addition, other accessories including oxygen cylinder, humidifier, suction device, etc., may be required depending on the need of individual patients. In designing the placement of the ventilator unit, safety of the mounting tray(s) and the overall stability of the wheelchair are primary concerns. In addition, the orientation of the ventilator must allow for adequate air intake, and the controls and displays at the front panel should not be obstructed by any fixtures. These additional weight of the ventilator components should be evenly distributed over the wheelchair frame.

Ventilator Placement

Ventilators are usually placed horizontally during normal operation and devices should not be mounted at an angle unless their performance in this position is guaranteed by the manufacturer. The space underneath the wheelchair seat is the obvious location for mounting the ventilator. Although chair frames can be retrofitted to create more space for the equipment, this implies major modification to the wheelchair structure, which can be rather expensive. Most ventilators can be fitted onto a 14 inches width manual wheelchair. To maximize use of the space underneath the seat of a common wheelchair, the ventilator and the battery are required to be mounted separately with trays on either sides of the cross brace. Self-locking drop-hooks can be used to secure the trays onto the chair. The equipment must be securely fastened onto the trays. If the chair has a rigid frame, the mounting trays can be designed to be permanently connected to the frame structure. The floor clearance for the trays should be at least 2 inches. When the ventilator is mounted at the rear which is the most common location, care should be taken to prevent it from being damage during the curb climbing maneuver. Sufficient clearance should be allowed between the seat upholstery and the top of the respiratory equipment, so that under occupancy, the body weight would not be transferred to the mounting fixture and the user would not be sitting on a hard surface.

In terms of power requirement, a 12VDC, 42AH battery is usually used. Modern design has reduced the overall dimension of these batteries, and they can be easily be fitted in front of the cross brace. As a safety measure, the two terminal connectors on top of the battery must be protected against any accidental contact with the wheelchair frame. Also, the position of the battery holder should not cause any obstruction to patient's legs, especially to those individuals with contractures. In addition, all respiratory equipment mounted onto reclining wheelchair has to be located below the level of the seat, so that the function of the recliner would not be limited.

Accessories

When oxygen is required for use, it is advisable to use the smaller cylinders. These must be properly secured but adequate provision should be made for their quick and easy interchange. The flow regulator should also be conveniently located. When the inhale air requires to be humidified, it is recommended that a humid vent device be used for the short period when mobility is essential. The jar type humidifier is excellent for longer term use but as it requires A/C power supply and uses a volume of hot water, it is not suitable for transport.

The length of the breathing tubing should be kept short to minimize the dead space. Also, the tubing should be routed and appropriately secured to prevent being disconnected or damaged during reclining and tilting of the seat as well as while the chair is in motion.

DISCUSSION

Three contrasting cases are used to illustrate the design considerations.

Child with Spinal Muscular Atrophy

This child requires a ventilator and a tilt-in-space chair with positioning support. The primary use of the unit is to allow him to attend school. Since his chair has a rigid frame, the ventilator and battery trays were directly attached using existing holes in the wheelchair frame. The breathing tube was routed from the back of the chair and, using a positioning clamp located on the side of the push handle, guided to the right side of his head. In order to prevent panel controls from being altered by other children, a quick release transparent protector was designed and installed. Since the child needs to be positioned at a particular angle for function, we decided to put a stopper to fix the tilt at an angle prescribed by the therapist. This would ensure that the caregiver can reproduce the desired tilting angle every time after transfer and also that, the seat frame will not accidentally touch the battery terminals.

Teenager with Cervical Spinal Fracture

This teenager has been hospitalized for a few years after he was injured during gymnastic exercise. As his condition stabilized, clinical professionals would like to improve the quality of his life by providing him with a manual recliner. Since the patient is very slim, the recliner is only 16 inches wide. Although the engineer was aware of the model prescribed, it was not known until the chair arrived that the only suitable location where the ventilator could be mounted was obstructed by the reclining lock mechanism. The solution was to swap the positions of the left and right lock mechanisms to create enough space, and to reposition the spreader bar further to the rear. Since the width of the wheelchair is maintained by the support structure of the mounting trays, the function of the spreader bar is actually enhanced despite of the minor modification. However, this modification has caused one problem. The lock mechanism failed to support the back post when the backrest angle exceeds 170°, and a stopper had to be installed to prevent shearing of the pivot pin when the backrest is in its full reclined position.

Integrating Ventilator with Manual Wheelchairs

Elderly person with Emphysema

This lady has been hospitalized for over two years and now requires a ventilator with oxygen supply to sustain her life. Due to the body build, her manual recliner has to be tailor made. As oxygen was required, two small cylinders had to be incorporated onto the wheelchair. It was found that the best location for placing the two oxygen cylinders was on the top of the ventilator. Although we suggested that the client should be provided with a rigid seat base, we still had to ensure enough clearance between the seat and the equipment to avoid any direct load transfer.

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SIG-02
Personal Transportation

SEATED POSTURAL STABILITY OF WHEELCHAIR PASSENGERS IN MOTOR VEHICLES

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ABSTRACT

The seated postural stabilities during driving maneuvers of quadriplegic, paraplegic, and able-bodied individuals were compared. Testing, conducted with the subject seated in a wheelchair in a 22-ft. van, consisted of left turns performed at two different speeds resulting in sustained centrifugal acceleration levels of either 0.2g or 0.4g. Subject response was captured in video recordings while vehicle acceleration was measured with a triaxial accelerometer. The quadriplegic subjects lost stability for all test runs, while the paraplegics withstood all the 0.2g and some of the 0.4g runs. The able-bodied subjects maintained balance for all runs. Better stability in the driving maneuvers correlated with an ability to withstand greater center of gravity displacement in static testing. For this small study seat cushion type had no significant effect on response.

BACKGROUND

While much clinical effort is expended to properly seat wheelchair users, the issues addressed primarily pertain to the static situation in which the client is at rest. New concerns may arise when the wheelchair user enters a dynamic environment, such as that inside a motor vehicle. Forces experienced inside a vehicle may greatly challenge the seated postural stability of a passenger or driver, thereby leading to fatigue, discomfort, or the jeopardizing of safety.

For individuals with reduced postural control, such as those with SCI, difficulties may arise even during normal driving conditions. When Sprigle and Linden tested the response of quadriplegic subjects to various driving maneuvers, they found that the subjects had trouble staying upright at very low acceleration levels[1-2]. However, they were unable to collect any kinematic data and did not examine any other disability groups.

The intent of this study was to begin to gather data, including kinematic information, on the effects of injury level and seat surface on postural control during driving maneuvers. Also, the authors wished to examine the efficacy of use of a static quantification of stability in predicting responses in the dynamic situation.

APPROACH

This study assessed postural control without use of the arms, thereby simulating events in which balance must be maintained while the arms are occupied with other tasks. Thus, instability was defined as the assumption of a posture from which a subject could not return to his resting posture without use of his arms. Balance was considered lost when a subject had to use his arms to prevent himself from becoming unstable.

A means for quantifying seated stability also had to be established. For the static environment, movement of the center of gravity, cg, was employed. The same wheelchair used in the vehicle testing was mounted to four load cells, as shown in figure 1. The subject rotated his trunk as far forward as possible up to the point of instability, and the corresponding cg movement was calculated. The protocol was then repeated with the subject leaning laterally.

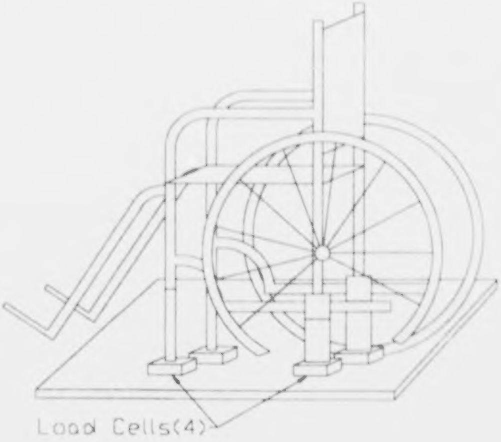

Figure 1: Apparatus for measuring maximum cg displacements which subject can withstand before losing stability.

In the dynamic environment degrees of stability were roughly quantified by conducting the left turn maneuvers at different speeds; this resulted in different lateral vehicle accelerations and, thus, larger disturbing forces being applied to the subject. Loss or maintenance of balance for a run at a given acceleration level was recorded. Also, if instability resulted, the amount of time for which the subject remained upright during the turn was computed.

METHODS

After the procedure for measuring balance in the static environment was completed, as outlined in the previous section, the experiments in the vehicle were conducted. The independent variables were the subject's functional level, the type of seat cushion, and the level of lateral vehicle acceleration. Chosen values are specified in table 2. Three runs were conducted for each combination.

Two male subjects from each of the three functional groups, quadriplegic, high paraplegic, and able-bodied, participated in this study. Subjects were instructed to keep their arms crossed in front of them while trying to maintain an upright posture during the turning maneuvers.

Runs were conducted both with the subject seated on a 3" foam cushion with a plywood base and on a high profile ROHO cushion. The seats were incorporated into a standard manual wheelchair with a sling back. The wheelchair, facing the front of the vehicle, was rigidly mounted in the bay of a 22-ft van to precluded possible confounding from wheelchair slide and tip.

Constant radius turning maneuvers were performed at two different speeds to create sustained 0.2g and 0.4g acceleration inputs to the wheelchair- subject system for 8 and 5 seconds, respectively. A sample curve of lateral vehicle acceleration vs time for a 0.4g turn is shown in figure 2. The 0.2g and 0.4g acceleration levels were chosen to represent the range seen in normal driving conditions as determined by on-the-road testing by this research group[3].

A video camera mounted on the van recorded subject response. Reflective markers were placed at the positions of the subject's ASISs, sternum, and coracoid processes. Images of initial position, voluntary response, and maximal displacement were digitized and analyzed for angles and displacements. Vehicle acceleration was measured with a triaxial accelerometer. A ramp voltage which was simultaneously sampled and displayed on a multimeter allowed for synchronization of acceleration and video data.

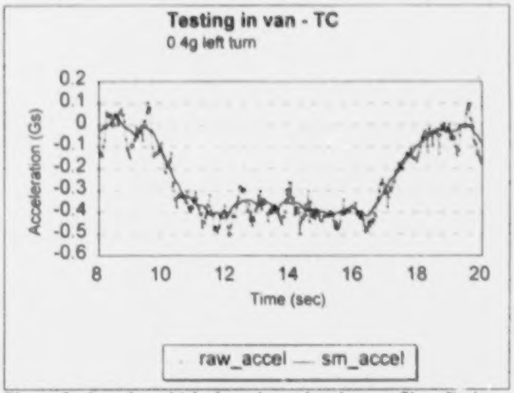

Figure 2: Sample vehicle lateral acceleration profile. Darker curve displays moving time average of raw data.

RESULTS

Static

The limits of cg excursion before loss of stability are listed in table 1. ΔXcg represents the displacement of the subject's center of gravity frontwards as the subject leaned in that direction. ΔYcg signifies the movement of the cg in the lateral direction as subject leans to his right. The able-bodied subjects, when leaning forward, were limited by the chest contacting the thighs rather than loss of stability.

Table 1: Cg movement subject can withstand before losing stability

Subject	Functional Level	ΔXcg	ΔYcg
MB	C5-6	0.3"	0.8"
TT	C7	0.2"	1.0"
JW	T4-5	1.3"	2.3"
TC	T5	1.1"	2.2"
TA	AB	4.5"	8.9"
MP	AB	7.5"	6.2"

AB : able-bodied subject

Dynamic

The results of the runs in the vehicle are summarized in table 2. The one set of tests conducted at the 0.4g level with the able-bodied subject on the ROHO produced results so similar to those observed with the foam cushion that no further testing was done with the able-bodied individuals on ROHO cushions. The paraplegics, while able to withstand all of the 0.2g turns, seemingly were pushed to their stability limit during the 0.4g turns. In the turns in which balance was

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lost, control was sustained until at least 50% of the turn was completed. One of the quadriplegics, MB, was also able to retain a stable posture through part of the turn, but only at the 0.2g level. On average he lost equilibrium 40% of the way through the turn.

Table 2: Number of runs for which subject remained stable

	Functional	Foam Cushion		ROHO Cushion	
Subject	Level	0.2g	0.4g	0.2g	0.4g
MB	C5-6	0	0	0	0
TT	C7	0	0	0	0
JW	T4-5	3	2	3	2
TC	T5	3	0	3	2
TA	AB	3	3	-	3
MP	AB	3	3	-	-

AB : able-bodied subject

Preliminary analysis of the kinematic data did not reveal any striking distinctions in body posture among the three subject groups or with use of the different cushions. Actually, initial postural response to the turn was quite similar in 5 of the 6 participants. These subjects compensated for the centrifugal forces by rotating their shoulders and upper torso clockwise 5-15° into the left turn. Figure 3 depicts this body position in an image capturing one of the quadriplegic subjects just before he enters the turn.

DISCUSSION

While the sample size for this study was too small to allow generalization of the results, some trends became apparent which warrant further investigation.

The three disability groups had very distinct responses both in the static and dynamic tests. The paraplegic subjects displayed a greater ability to maintain equilibrium while shifting their center of gravities in the static testing than the quadriplegic subjects. While the increased cg displacement was small when compared to the values attained by the able-bodied participants, it translated into significantly improved postural control during the vehicle testing in comparison to the quadriplegic subjects.

Our results showed no significant overall differences between responses obtained with the subject seated on the ROHO or foam cushions.

Preliminary investigation of body angle and displacement data suggested some similarity in seated postural control strategy among the different subject groups. Further testing may lead to the identification of representative kinematic responses.

Figure 3: MB entering 0.2g left turn. Arrow represents direction of centrifugal acceleration.

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THE AFFECTS OF SECUREMENT POINT LOCATION ON WHEELCHAIR CRASH RESPONSE

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ABSTRACT

ADA has led to an increase in disabled travelers, many of whom are required to use their wheelchairs as vehicle seats. Proper securement of the wheelchair is crucial to the safety of these wheelchair users in a crash. To promote proper wheelchair securement, the ANSI/RESNA Transportable Wheelchair Standard currently under development will require that all transportable wheelchairs be equipped with four securement points, compatible with belt-type tiedowns. Through computer simulations, the location of these securement points has been found to influence the response and loadings of a wheelchair in a frontal crash. Accordingly, placement of securement point locations by wheelchair manufacturers can serve as a strategy to control crash response, and may eliminate the failure of critical wheelchair components in a crash.

BACKGROUND

With the advent of ADA many wheelchair users are seeking both public and private transportation to access employment, particpate in leisure activities and carry out the needs of daily living. In doing so a large number of these travelers are unable to transfer from their wheelchairs to a vehicle seat and are therefore required to remain in their wheelchairs during transport. By using a wheelchair as a vehicle seat, the wheelchair is required to meet new performance capabilities for which it may not have been originally designed. In an effort to establish design and performance criteria for wheelchairs used in transportation, ANSI/RESNA is currently developing a Transportable Wheelchair Standard. As an initial requirement, the ANSI/RESNA standards committee intends to require that transportable wheelchairs must be equipped with four securement points compatible with belt type tiedown securement systems.

Currently vehicle operators must select the points on the wheelchair which they believe will provide adequate and safe securement during normal driving manuevers as well as in a crash. Compliance with the ANSI/RESNA Standard will eliminate the "guess–work" associated with this process by providing four easily accessible securement points for repeated use. Since these securement points will become a permanent part of the wheelchair, it is prudent that insight to selecting the placement of these points be provided. To assist wheelchair manufacturers in establishing securement point placement, this study investigates the affects of securement point location on wheelchair response and loadings during a crash. Consequential tiedown loadings as a result of securement point location are also examined.

RESEARCH QUESTION

This study seeks to determine the influence of wheelchair securement point location on wheelchair crash response, as well as wheelchair and tiedown loadings during a crash event.

METHODS

To evaluate the effects of rear securement point location on the crash response of a wheelchair, a lumped mass model of the SAE surrogate wheelchair (1) with a 50th percentile male Hybrid III anthropomorphic test dummy was employed. The SAE surrogate wheelchair, a structurally enhanced wheelchair, was constructed for the purposes of repeated sled testing to evaluate the performance of wheelchair tiedowns and occupant restraints (WTORS). Wheelchair securement in the model is accomplished using a four point tiedown system, while the occupant is restrained with an integrated lap belt and vehicle mounted shoulder belt. This model (2), developed for research associated with the SAE J2249 Wheelchair Tiedowns and Occupant Restraint Standard (3), uses the Articulated Total Body/Crash Victim Simulator code (Wright-Patterson Air Force Base). Validation of the SAE surrogate wheelchair model has been conducted through interlaboratory sled impact testing (4). The model subjects the vehicle transporting a forward oriented wheelchair and occupant, to a 20g, 30 mph frontal crash.

Using the wheelchair/occupant model described above, simulations were run with the rear securement point height at 7.5" above the wheelchair center of gravity, level with the center of gravity (CG), and 7.5" below the center of gravity. Although these conditions may represent the extreme of securement point locations for actual installations, they provide insight as to the trends which occur in a crash. For each case, response of the wheelchair and it's occupant are recorded, while front and rear wheel forces, front wheel vertical displacement, and tiedown forces are evaluated.

RESULTS

A pictorial representation of each of the three simulations with varying rear securement point height is shown in Figure 1 at 90 msec into the crash event. Case A which secures the wheelchair above the wheelchair CG tends to rotate the wheelchair and occupant counterclockwise, or rearward. Conversely, Case C which places the securement below the CG tends to rotate the wheelchair forward. Locating the securement point at the same height as the vertical wheelchair CG as depicted by Case B, provides the most controlled wheelchair response to a crash.

Peak wheelchair excursions and loads associated with each of the simulations are provided in Table 1 through a time of 120 msec. Plots of each evaluated

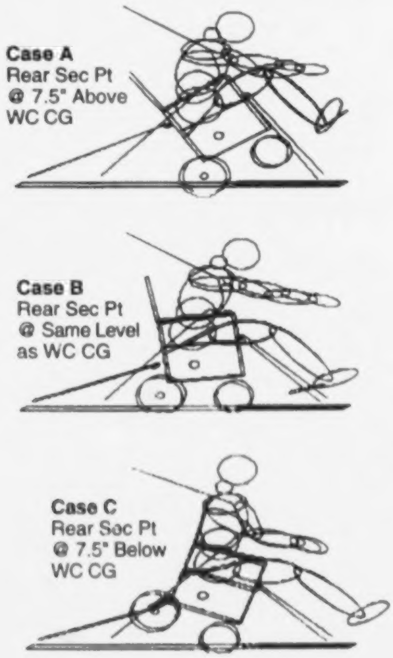

Figure 1. Wheelchair-Occupant Response for Varying Rear Securement Point Heights

parameter are shown in Figures 2 through 4. Figure 2 shows that maximum rear wheel forces decrease as the securement point is moved from a point 7.5" above the wheelchair CG, to a point 7.5" below the CG. This type of relationship is as expected since as shown by Figure 1, the wheelchair and occupant rotate about the rear wheel when the securement point is above the CG (Case A), leading to an excessive peak rear wheel loading of 7399 lbs. Front wheel loading is negligible in Case A since the wheel is lifted off of the floorboard during the crash. Moving the securement point to below the CG (Case C) causes the wheelchair to rotate forward on the front wheel, reducing the maximum rear wheel loading to only 118 lbs. However, this relief of rear wheel loading upon forward rotation of the wheelchair is accompanied by an increased front wheel peak loading of 2022 lbs.

Table 1. Affects of Varying Wheelchair (WC) Tiedown Securement Points (t=0 to 120 msec)

Parameter	**Case A**	**Case B**	**Case C**
WC Vertical CG	12.9"	12.9"	12.9"
Rear Sec Pt Ht	20.4"	12.9"	5.4"
Front Sec Pt Ht	19.7"	19.7"	19.7"
Diff Betw Rear Sec Pt & WC Vert CG	7.5" Above	0"	7.5" Below
Lap Belt Anchor	On WC	On WC	On WC
Maximum Wheel Forces			
Rear Wheel	7399 lb	1795 lb	72 lb
Front Wheel	118 lb	1348 lb	2022 lb
Maximum Front Wheel Displacement			
Vert Displacement	4.8" Up	1.2" Dn	1.7" Dn
Maximum Tiedown Forces			
Rear Tiedown	7000 lb	4728 lb	4513 lb
Front Tiedown	6170 lb	22 lb	22 lb

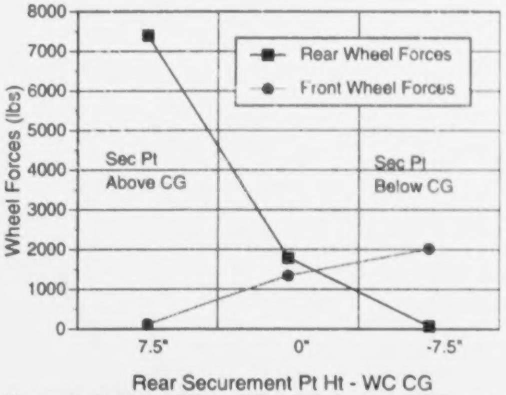

Figure 2. Front and Rear Wheel Forces vs. Difference Between Rear Securement Point and Wheelchair Vertical CG

The motion of the wheelchair during the crash event can be captured by evaluating the wheelchair front wheel excursion. Figure 3 shows that the front wheel hub rises 4.8" above it's initial position when the securement point is above the wheelchair CG as in Case A. This result occurs since rearward, or counterclockwise rotation of the wheelchair tends to lift the front wheel upward. Conversly, the forward rotation associated with Case C which locates the securement point below the CG, causes the front wheel to be depressed into the floorboard. This deformation produces a downward deflection of the front wheel hub equal to 1.7". The controlled response of the wheelchair under conditions where the securement point is at the same level as the CG, can be confirmed through the minimal front wheel downward excursion of just 1.2".

Tiedown forces are also affected by location of the securement point as shown by Table 1 and Figure 4. Placement of the securement points above the wheelchair CG produces the largest tiedown forces of the three scenarios. In Case A, maximum front tiedown forces are 6170 lbs., while rear tiedowns experience a peak loading of 7000 lbs. (Since an integrated lap belt adds the load of the occupant to the wheelchair tiedowns, resulting tiedown loads are greater than in a scenario where an independent lap belt is used.) This relatively high loading placed upon the front tiedowns is due to the rearward rotation of the wheelchair which must be countered by the front tiedowns. Relocating the securement point to below the CG decreases the maximum force imposed upon both the front and rear tiedowns. In this scenario (Case C), front tiedown loads are negligible and rear tiedown loads are reduced to 4513 lbs. This decrease

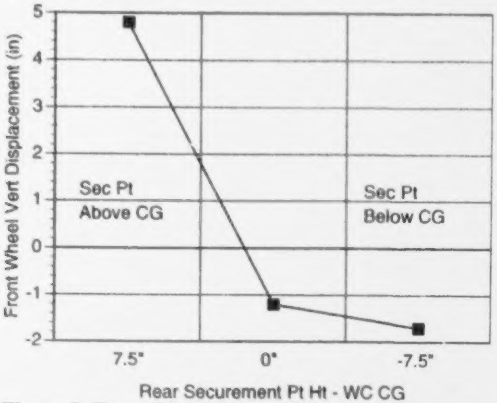

Figure 3. Front Wheel Vertical Displacement vs. Difference Between Rear Securement Point and Wheelchair Vertical CG

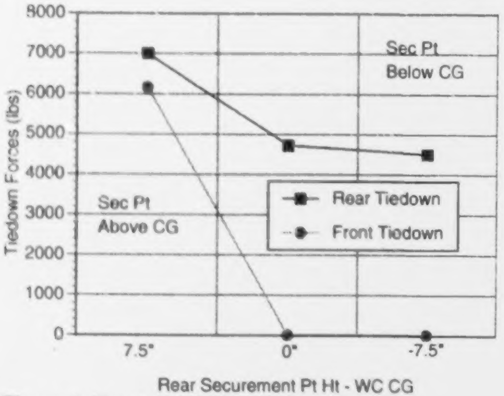

Figure 4. Front and Rear Tiedown Forces vs. Difference Between Rear Securement Point and Wheelchair Vertical CG

in maximum rear tiedown loading is close to a 36% reduction when compared to Case A maximum loads.

DISCUSSION

Results of this study indicate that rear securement point location relative to wheelchair CG can influence loads experienced by both the wheelchair and securement system in a crash. Selection of securement point location on the wheelchair is critical since differences in wheelchair component loadings may equate to failure in a crash. Wheelchair crash component forces, such as those experienced by the front and rear wheels, vary greatly depending upon rear securement point location. For example, maximum front wheel forces are shown to increase by more than 1600% with moving rear securement points from 7.5" above the CG, to 7.5" below the CG. Failure of components critical to wheelchair stability in a crash, such as casters, can lead to excessive occupant excursion. It is these excessive excursions which often result in "secondary impact", or occupant impact with vehicle surfaces, that cause serious injury.

Rear securement point placement has also been found to influence the dynamic crash response of the wheelchair. With rear securement at the level of the vertical CG (Case B), wheelchair response to the crash is relatively controlled as compared to Cases A and C which secure the wheelchair above or below the CG. The controlled response in Case B can be accounted for since the rear tiedown more directly opposes the forward crash forces of the wheelchair which are concentrated at the CG. Eccentric location of the securement point relative to the wheelchair CG will induce a moment causing the wheelchair to rotate as seen in Cases A and C. Increasing the distance between the CG and the securement point serves to increase the moment arm, thereby increasing the rotating moment.

Wheelchair securement point locations also affect the loads which securement systems must withstand in a crash. In designing securement systems, manufacturers must be aware of the consequences associated with poor placement of securement points. Placement of securement points above the CG to the extend of that in Case A, for example, will tend to lead to front tiedown loads which are higher than typically expected since front tiedowns must resist the severe backward rotation of the wheelchair.

To comply with the ANSI/RESNA Transportable Wheelchair Standard, wheelchair manufacturers will soon be required to provide securement points on wheelchairs intended for transport. As shown by this study, locating the rear securement points at or close to the height of the wheelchair vertical CG can improve the response of the wheelchair and occupant to a crash. Additionally, when securement points are placed at the vertical CG level, wheelchair and tiedown loadings can be better managed.

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TRANSPORTATION NEEDS: SURVEY OF INDIVIDUALS WITH DISABILITIES

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Abstract

In order to evaluate the transportation needs of individuals with disabilities, a survey was distributed to the mailing list of the local independent living services organization. In addition to basic demographic data, respondents were asked to report their modes and frequency of travel, fatigue information, seat belt use, driving frequency and accident rates. The results of the survey showed that all respondents use personal vehicles as drivers or passengers for transportation, while two-thirds use public transit. Respondents had a greater tendency to travel while seated in their wheelchairs when using public transit, and reported having difficulty with wheelchair securement and occupant restraint systems in all vehicles. The ability to leave the vehicle in the event of an emergency was also a major concern. Additional attention to comfort, ease of use, and emergency egress is necessary for wheelchair securement and occupant restraint systems, particularly for public transit vehicles.

Background

Transportation plays a vital role in an individual's ability to participate in society. The ability to travel outside the home allows opportunities for employment, recreation, and fulfillment of needs. The current focus in transportation research for individuals with disabilities is to provide the mobility aid users in personal vehicles with adequate protection in the event of an impact. While this issue is of great importance, the daily transportation needs of individuals with disabilities involves other concerns, for example availability and affordability of personal vehicles, scheduling of public and paratransit services, acquisition and management of appropriate adaptive equipment, and ease and comfort of wheelchair securement and occupant restraint. This paper begins to investigate some of these issues by reporting results of a survey of individuals with disabilities.

Research Question

The objective of this survey was to assess transportation issues for individuals with disabilities from the perspective of that population. Analysis of this information provides direction for future transportation research.

Methods

Individuals with disabilities were surveyed in order to evaluate their transportation needs. The survey was mailed with the local independent living service's newsletter. Since this was intended as a pilot survey, follow-up solicitation was not performed. Approximately 1.5% of the 5,000 surveys mailed were returned.

The survey requested information regarding basic demographic data: age, sex, and disability. Return postmarks were used to determine the geographic distribution of the respondents. The survey contained questions regarding travel frequency, driving frequency, seat belt use, and accident rates. Use of public and personal transportation was determined. Additional questions related whether the respondents transferred while traveling to type of mobility aid used and mode of transportation (personal or public transit). Open ended questions allowed free response regarding barriers to seat belt use and driving, as well as general traveling difficulties and safety concerns.

Survey responses were maintained on a database which facilitated searching and indexing of responses to multiple questions. In the results reported below, responses to each question may not total 100% because respondents frequently did not answer all survey questions.

Results

The population responding was approximately 35% male and 65% female. Sixty-three per cent of the respondents resided in the Cleveland metropolitan area, with an additional 11% from Ohio, and 15% from other states. Non-legible post-marks account for the remaining responses. The respondent's age (Table 1) and disability group (Table 2) were categorized. In addition to the disability groups shown, 8% did not list their disability, while approximately 20% of the responses provided sole representation of their disability group.

Table 1: Age of respondents

under 20	7
20-29	10
30-39	20
40-49	20
50-59	18
over 59	22

Table 2: Disability Groups

Spinal Cord Injury	21
Polio	18
Multiple Sclerosis	14
Cerebral Palsy	11
Head Injury	4
Muscular Dystrophy	3
Stroke	3
Spina Bifida	3
Arthritis	3

All of the respondents reported using personal vehicles either as drivers or passengers, while 56% of the respondents use public transit. The majority (62.5%) use transportation daily either as a driver or passenger. Although 22% of the respondents do not drive or use public transit, approximate 40% of this group travels on a daily basis and an additional 40% travel several times a week.

Approximately half (51%) of the respondents do not drive. The most common barriers to driving reported by non-drivers were limited range of motion (54%), financial reasons (41%), weakness (38%), and lack of balance (32%). Of those who drive, 47% drive cars, 32% drive modified vans, 12% drive vans, and 7% drive minivans. Sixty-five per cent of these individuals have not been involved in an accident in the past five years, while only 6% had been involved in more than two and none had been involved in more than four accidents. Over half (54%) of those who drive also use public transit.

Seat belt use is summarized in Table 3. Encouragingly, 69% reported always using a seat belt. Contributing reasons cited included safety (83%), to comply with the law (44%), and to provide balance (43%). Reasons cited for not using seat belts were difficulty in application (13%), discomfort (11%), and interference with driving or other activities (4%).

Half of the respondents reported using a manual wheelchair during transportation, while 29% used power wheelchairs, 15% used scooters, and 7% did not use a mobility aid. Table 4 shows respondent transfer characteristics based on type of mobility aid used for personal and public transportation. In general, for all traveling in their wheelchairs 60% use public transit and 40% use personal vehicle transportation.

Table 3: Summary of Seat Belt Use

Seat Belt Use	
Always	69
Often	10
Sometimes	4
Never	7
To Drive	6
As Passenger	1

Table 4: Percent of Respondents who Travel in Wheelchairs

	Manual WC	Power WC	Scooter	Total
Public Transit	14	21	25	60
Personal Transit	6	22	43	40
Totals	20	43	37	100

Sixty-five per cent of the respondents reported having at least minor problems maintaining balance, while 29% reported no balance problems. Sixty-seven per cent of those without balance problems drive, while only 40% of those with balance problems drive.

Open ended questions requested the respondents to report the aspects of transportation which they found most difficult or unsafe. Vehicle ingress and egress including loading mobility aid into the vehicle and transferring to the vehicle seat was the most frequently reported difficulty, with 20% of the respondents citing this. Seventeen per cent of the respondents reported safety concerns with wheelchair securement and occupant restraint systems, including issues such as ease of use, the ability of the wheelchair user to release these systems in the event of an emergency, and training of public transit vehicle operators in correct securement and restraint techniques. An additional 7% reported their biggest transportation difficulty was scheduling rides and finding appropriately trained drivers.

Discussion

While this pilot survey provided a relatively small sample size and geographic distribution, trends in the data can begin to be identified. Future surveys will continue to address specific questions and distribute the survey to a much broader population.

The majority of the individuals surveyed travel on a daily basis even though over half do not drive and approximately a quarter of those do not use public transit. It is assumed that these individuals are scheduling rides with others or private transit services. It is possible that many of these individuals could use public transit as more public transit providers become compliant with the ADA and travel training programs are utilized.

An individual's desire to transfer to a vehicle seat for travel can be related to their type of mobility aid and whether public or personal transportation is used. As shown in Table 4, wheelchair users have a greater tendency to travel while seated on their mobility aid when using public transit. Since the larger percentage of those traveling in their wheelchairs are using public transit, an increased priority should be placed on addressing wheelchair securement issues for public transit vehicles.

The most common reason reported for not using seat belts was difficulty in their application. Additionally, using wheelchair securement systems was one of the most frequently cited difficulties. Concern was also expressed over release of securement system and vehicle egress in the event of an emergency. Further work is needed to ensure that wheelchair securement and occupant restraint systems are easy and convenient to use and can be released by the wheelchair user in the event of an emergency.

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SIG-03
Augmentative & Alternative Communication

ADDING USER PROGRAMMABILITY TO A DEDICATED AUGMENTATIVE COMMUNICATION DEVICE

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ABSTRACT

An augmentative communication (AAC) device has been enhanced with sophisticated macro capabilities. Previously, the system was capable of creating macros which could execute any combination of operations normally available to the system operator. This included a macro recorder which enabled the system operator to create a macro simply by performing the desired sequence of operations using the system's standard interface. A number of new features have been added to the system which significantly increase its power and programmability. These include: control structures WHILE/ENDWHILE and IF/ELSE/ENDIF; user-definable variables; complex expressions including arithmetic, logical, and string manipulation operators; and a variety of hooks into the operating system (e.g. switch and keyboard events). A number of "application macros" have been developed to test and demonstrate the power of the system.

BACKGROUND

Devices which have been specifically designed to serve as AAC systems generally have a number of characteristics such as improved durability, extended battery life, and control interfaces which have been optimized for individuals with severe motor impairments. Operating systems for such devices include a variety of functions which have been designed to be potentially useful for such individuals, especially for face-to-face communication. While such dedicated systems are not generally able to run standard computer applications, keyboard- and mouse-emulating interfaces can be used to enable such systems to be used for computer access. This allows the same language interface used for communication to be used for text generation on a computer.

Many tasks performed by system operators involve the repetition of simple functions, or repeated sequences of functions that vary in a fixed or predictable manner. Such tasks are obviously good candidates for software implementation. However, this is generally not an option since most dedicated systems support the selection of various features and options, but lack the ability to program truly novel modes of operation. The needs of system operators vary so greatly that it is simply not feasible to include in an operating system every possible combination of functions, features, and/or modes of operation that might prove useful to some individual. An alternative is to provide a macro language which is flexible and powerful enough to enable the end user or other support personnel to implement solutions to support such tasks.

A major revision of the operating system has been developed for a device which uses semantic compaction as the primary vocabulary organization technique. The previous revision included extensive macro capabilities, including a macro recorder which enables the creation of a macro by performing the desired sequence of operations using the system's standard interface. However, the ability of the macro language to respond to operator input was limited to allowing selections from system menus, selecting icons in certain situations, and entering text strings requested by the operating system. One of the primary goals of the new revision was to enhance the macro capabilities to provide the functionality described above. Once this was achieved, it was found that some of the other features to be included in the revision could be implemented using macros, and did not require further modification to the operating system software.

STATEMENT OF THE PROBLEM

The device in question has been used in field for over four years. The developers have been in close contact with a wide range of system operators during that time, and have responded to a large number of requests for operational modifications to the system. On many occasions, such requests have been able to be satisfied immediately by providing a macro to perform the desired function. However, these requests have often required revisions to the operating system (which is stored in flash EEPROM in the device, and can be upgraded in the field). Such revisions are only released periodically, so such requests may actually be satisfied only after a lengthy delay.

RATIONALE

In order to satisfy such user requests in a more timely fashion, it is necessary to support true programmability at the macro level in the device. This required the implementation of a number of new functions and features, many of which were well known at the outset of defining the enhancements. The first requirement was to introduce basic program control structures. To keep the programming language as simple as possible, only WHILE/ENDWHILE and IF/ELSE/ENDIF were used since all of the needed programming constructs could be created from these. User-definable variables were another necessary addition, along with the ability to process complex expressions including arithmetic, logical, and string manipulation operators. A variety of hooks into the operating system were also needed such as switch and keyboard events, and the ability to test and manipulate various system resources such as text and icon buffers. Other needed functions included the ability to delay for fixed intervals and to wait for specific events. The need for additional specialized functions became apparent only after some experience of trying to program specific macro functions using the first version of the revised system. Some of these examples will be described in this paper.

DESIGN / DEVELOPMENT

Previous versions of the operating system already supported the creation of "named macros" which can be invoked from other macros using the function ◀MACRO(m_name)▶. A single named macro is limited to a maximum length of 246 bytes. This results in a "natural modularity" since more complex procedures must be broken down into functional components. In any case, since the system's display is limited to an 8-line LCD screen, this approach is more manageable at the programming level than large monolithic blocks of macro code. It also tends to be more efficient since many modularized macro functions may be re-used in other complex macros.

The two programming structures available in the macro language are IF/ELSE/ENDIF and WHILE/ENDWHILE. Since the macro "code" is interpreted rather than compiled, one constraint of the system is that the matching parts of a single control structure must occur within the same named macro. Since the body of a structure can consist of a call to another macro, this does not limit the capabilities of the system. Furthermore, attempting to construct macros that violated this requirement would be both difficult and highly error-prone. Other functions that affect the flow of execution include ◀MACRO-EXIT▶, which immediately returns to the macro which invoked the current macro, and ◀MACRO-RETURN▶, which does the same but first calculates and returns the value of the following expression, which can be of any type (integer, floating point, character or string). The type of the return value is automatically recognized by the expression evaluator, and converted appropriately when necessary. ◀MACRO-QUIT▶ exits all the way up to and out of the top level macro, so that the system waits for the next user input. ◀PAUSE▶ evaluates the following expression as an integer and unconditionally waits for that many 1/64's of a second. ◀WAIT-EVENT▶ must be followed by an event specifier, and optionally by a time-out limit (in 1/64's of a second). The ◀ANY-EVENT(...)▶ (or ◀ALL-EVENTS(...)▶) function specifies which combination of switch and/or keyboard events is of interest and waits until any one (or the entire set) of the events specified occurs (or until the time-out limit expires). Finally, it is possible to specify a "start-up" macro that, if it exists, is automatically invoked every time the device is powered up.

Simple temporary variables are set up for convenience to initialize and use "locally" within a single macro "program." User-defined, named variables can be created as needed to store values which serve specific functions. They may be set up as arrays, and can be initialized to more complex sets of data (such as the number of days in each month, or an array of macros). Variables can be set to expression values, or the user can be prompted to input a value. A variety of random number generation functions are available for implementing games, therapy drills, and so forth.

One set of specialized functions was created to test and manipulate various system buffers and interfaces. The characters in the neighborhood of the text cursor can be tested and manipulated, as can the icons in the icon buffer and the data structure controlling which LEDs in the keyboard matrix are lit ("icon prediction"). One example macro using such functions simply spells out loud the word under or preceding the text cursor (e.g. for spelling an unfamiliar name over the telephone). For an early emerging literacy application, the speech output could be "A as in apple, T as in...", and so forth. Another macro pluralizes the preceding word, generating the correct spelling according to the morphology of the word.

One system operator who utilizes auditory scanning for his selection technique requested that the system be set up to read the complete contents of the icon buffer as each new icon is added that does not complete an icon sequence. To accomplish this with a macro required that the macro be continuously executing "in the background," which meant that the macro needed to be able to fetch keystrokes, have the system perform them, and then test the result to see if the icon buffer was to be spoken. The ◀KEY-FETCH▶ and ◀KEY-

PERFORM▸ functions were created to fill this need, and have been found to be useful in a variety of similar applications in which the macro executes in the background. It is also possible to generate informative messages that appear as if they were generated by the operating system.

Fraser Shein has noted that, for an individual who uses scanning as their input technique, it is much more efficient to directly scan and manipulate the text itself, rather than to scan a separate keyboard matrix to select functions which move the cursor through the text [1]. A macro was developed to implement this approach, making frequent calls to a macro which simply waited until the switch was depressed, then returned 0 or 1 depending on whether the switch was depressed for a time exceeding a certain threshold (set in a named variable). By responding to audible prompts from the macro, the system operator can choose to move forward or backward, then choose how many paragraphs, sentences, words, and finally letters to move the cursor.

A more complex example implements a completely new selection technique which enables the operator to use a joystick to navigate through a hierarchical system of categories based on auditory prompts. Moving the joystick to one of the eight compass points generates the auditory prompt for the category or selection item at that node. If the joystick is held in that position past a pre-set time threshold, that category or item is selected. If nothing has been programmed at a given node, the prompt "empty" is automatically generated, and the system remains in the current category.

Two other features have been added to enhance the utility of the macro system. One is user-definable alarms which can be set up to trigger any macro. They can be set up as one-time only alarms, or to repeat at any desired frequency. They can be programmed to trigger only when the device is turned on at the time of the alarm, or to turn the device on, or to wait until the device is manually turned on. The other feature is the ability to create "menu macros." The operating system interface commonly uses menus on the 8-line LCD as the interface for configuring system options. Menu macros allow the programmer to create a similar "look and feel," where each menu selection triggers a macro. Thus, a menu system might be created in which each selection sends a command out the serial port to an environmental control device, organized as a menu of devices with sub-menus of relevant commands.

As a final example, a background data collection macro has been created at the request of a number of different researchers. The macro is designed to time-stamp and record every event of interest (switch closures, key selections, text generated, speech output, etc.) in order to collect data for research purposes. The data is recorded in a hidden file in the background which can be downloaded to a computer for later analysis. To enable this macro to perform this function without distracting the system operator, a number of very specialized functions had to be added. These included functions to: save and restore the state of the system (before and after recording the data for each event); automatically record and subsequently duplicate any text and/or speech generated by a key selection, and to temporarily disable the system from modifying or refreshing any visible display (to keep the display and LEDs from flickering during the data recording process).

EVALUATION

Formal beta-testing of the system began in July, 1995, and has been in daily use by about 20 system operators ranging from young children to adults. It has also been demonstrated to a large number of professionals, including several speech language pathologists specializing in AAC. Much useful feedback has been received resulting in the improvements and refinements described above. General release of the operating system is scheduled for the spring of 1996.

DISCUSSION

The purpose of the enhanced macro capabilities of the system is to provide a simple, rapid and generally available method for developing customized functions for a widely used, commercially available AAC device. A number of complex and arguably useful "application macros" have been developed and tested. The system has been enthusiastically received by the individuals involved in beta-testing. It is anticipated that a disk of "shareware" macros will be developed over time to facilitate the widespread distribution of macros found to be particularly useful.

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A PRELIMINARY STUDY INTO SCHEMA-BASED ACCESS AND ORGANIZATION OF REUSABLE TEXT IN AAC

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Abstract

Augmentative and Alternative Communication systems must, to be effective, support a rich language model that among other things recognizes that much of our conversation is reusable. This means that whenever possible previously composed messages (e.g., sentences) must be easily retrieved rather than typed from scratch. One approach to reusable conversation uses the notion of schema-based structures that recognizes that many of our activities, including conversations, can be seen as an ordered sequence of actions. These schemata are often partially specified so that adaptation to the specific situations is possible. This paper described a prototype implementation based on schema theory and the preliminary results of a two user evaluation in a role-playing situation.

Background

The field of AAC technology research and development can be broadly classified into three areas: 1) physical interfaces; 2) language models; and 3) output. While progress in all areas is essential for the development of effective systems, language is central to the operation of the system and represents the most active area of AAC research. By language model we are considering: 1) the basic "language units" (e.g., letters, words, phrases); 2) how they are represented (e.g., text, graphics); 3) how they are organized; 4) what additional processing the system does based on user selections (e.g., prediction). In the last decade, researchers have begun to understand the need for more sophisticated language models in AAC. One striking example is the notion of "reusable conversation" introduced by the University of Dundee which recognizes that, despite the enormous flexibility of language, much of what we say, we have said before[2].

Research into reusable conversation has emphasized two major areas:

- high frequency and typically short utterances such as greetings [2]; and
- lower frequency, but longer length narratives such as stories and jokes[3].

While these types of conversational material are extremely important, there is still an enormous range of contexts that have not yet been sufficiently addressed. For example, the general task of ordering take-out food on the phone will include many "canned" pieces such as giving your address. However it will also have many less predictable components such as the specific food that you are ordering which will depend on the specific restaurant called and that moments preferences. These situations are characterized as being partially structured. You may say roughly the same things in roughly the same order, but there will also be numerous differences each time the situation occurs.

In our work we attempt to organize and thus give access to reusable texts by storing the text in "schema" structures. In the field of Artificial Intelligence, Schank and his students [5] developed the notion of a schema as a typical sequence of events associated with stylized activities. For example, going to a restaurant contains an entering, ordering, eating, and exiting scenes. Each scene in this schema contain sequences of actions which are typical in the restaurant domain. Schema theory can be applied to AAC text organization by associating text with the activities captured in the schema

A prototype system called *SchemaTalk* has been developed. It is described below and in more detail by Vanderheiden [6]. It differs from other recent work on schema based organization by Alm and colleagues [1] in a number of ways. Most importantly, it allows partially specified sentences that can be filled with content appropriate words. The purpose of this paper is to describe the first evaluation of the system.

Approach

SchemaTalk is a stand-alone application that can be accessed from a computer or AAC system. A product-oriented version would be more tightly integrated with the AAC system so that functions such as speech synthesis would not need to be duplicated. However, for research purposes, this configuration is most flexible.

Schemata are constructed by the user and stored in a separate text file. Motivated by Schank [5], several levels of schematic structures are available to the user. A hierarchy of MOPs (Schank's "memory organization packets") constrains the global context. Each MOP can contain a sequence of scenes and a list of slots. A scene contains a sequence of sentences (and sentence templates), while a slot contains a list of fillers.

When a MOP is chosen from the MOP list, the first scene is entered, and the first sentence of that scene is highlighted. The user can advance from one sentence to the next, or to the previous sentence. The user can also advance to the first sentence of the next scene or the previous scene. Kellermann et al. [4] suggested that scenes are weakly ordered in conversation. Therefore, the user also has the option of calling down a list of scenes (or MOPs) and directly selecting the next one to go to.

Slots and fillers have two purposes in SchemaTalk. First, they enable the user to prestore related words or phrases. For example, an avid sports fan could list the names of teams in the slot "team names." Second, a slot can be associated with a particular location in a sentence to create a sentence template.

When a sentence template is selected, the list of fillers for a given slot is displayed. For example, choosing the sentence "Who wants to watch the <team names> play on tv at my house?" causes the list of team names to be displayed. Then choosing "Toronto Blue Jays" completes the sentence. Sentence templates reduce the number of selections required to produce a sentence. They also reduce the need to store and scroll through long lists of sentences, had each template filler been stored separately.

The SchemaTalk interface is written in Tcl/Tk and C++ in a UNIX environment, and appears as a single window on a computer display. Dialog boxes containing lists of MOPs and scenes appear when called, while sentences for the current scene or fillers for the current slot are displayed as a scrolled list in the main window.

Evaluation Method

In order to make a preliminary evaluation of the SchemaTalk approach, a series of mock interviews was carried out. Two subjects participated, one with physical and speech impairments, and one without. We refer to them here as S1 and S2. The idea was to see if the subjects could develop schemata and use them effectively in a "real world" situation.

S1 and S2 were each interviewed multiple times for a sportswriter's position at ESPN, a television sports channel. Staff at the laboratories played the role of interviewer. S1 and S2 were required to produce all of their verbal communication using SchemaTalk. All interviews were recorded on videotape and then transcribed.

S1 normally uses a commercially-available augmentative communication system to speak. He has had no previous experience in interview situations, although he has a strong interest and extensive knowledge about sports. He is 39 years old and produces fairly complex sentences, but has difficulty with spelling and grammar. S1 had not previously spoken with any of the interviewers. In order to use SchemaTalk, S1 was required to learn commands for controlling a computer from his AAC system (using a mouse / keyboard emulator) in addition to learning how to control SchemaTalk itself.

S2 is a staff member at the laboratories who speaks using his natural voice and has never participated in a real job interview. S2 is 29 years old and has no disabilities or language difficulties. S2 was familiar with all of the interviewers. Although S2 could control SchemaTalk directly from a computer keyboard, he was required to type using a mouse-controlled on-screen keyboard. This set a minimum of approximately 1 character per second on his typing speed.

Although no time limit was given for an interview, a guideline of one hour was suggested. S1's interviews all lasted about the entire hour while S2's interviews were shorter. Nevertheless, the two subjects produced approximately equal numbers of words.

In the first interview, subjects directly entered their text: S1 used his augmentative communication system and S2 used the on-screen keyboard. There were a few discrepancies in the conditions for the two subjects in the second interview. In interview #2, S1 used a simplified SchemaTalk interface that contained his sentences from interview #1 and a practice interview in the form and order in which they were originally produced. This was intended to give him some practice controlling the interface and interacting with it using his AAC system. In contrast, S2 was given the complete SchemaTalk interface in interview #2 and allowed to access sentences he had previously organized into schemata. In the remaining interviews, both S2 and S1 were able to access sentences they had previously organized schematically. Because S1 was not familiar with schemata organization and computers, S1's organization was developed in conjunction with one of the authors.

Results / Discussion

In analyzing the interviews, we were interested in how SchemaTalk (and access to sentences organized by schemata) would affect the user's communication patterns. Several measures are listed in the following tables., In each table we differentiate between words generated by (1) selection using SchemaTalk alone,

	Interview	#1	#2	#3	#4
Turn Count (turns / interview)	schema	N/A	6	1	5
	mixed	N/A	1	2	2
	direct	23	2	5	6
	other	20	3	17	11
	TOTAL	*43*	*12*	*25*	*24*
Word Count (words / turn)	schema	N/A	19.8	20.0	23.0
	mixed	N/A	24.0	32.0	32.0
	direct	10.0	10.5	16.2	19.2
	TOTAL	*10.0*	*18.2*	*20.6*	*22.6*
Speech Rate (words / min)	schema	N/A	4.6	14.6	13.8
	mixed	N/A	2.8	6.6	6.4
	direct	4.5	1.7	2.3	3.1
	TOTAL	*4.5*	*3.5*	*3.6*	*5.3*

Table 1: Summary of Results for S1

	Interview	#1	#2	#3
Turn Count (turns / interview)	schema	N/A	7	11
	mixed	N/A	2	3
	direct	22	17	5
	other	0	3	0
	TOTAL	*22*	*29*	*19*
Word Count (words / turn)	schema	N/A	11.0	5.4
	mixed	N/A	14.5	29.0
	direct	10.7	3.9	17.0
	TOTAL	*10.7*	*6.6*	*12.2*
Speech Rate (words / min)	schema	N/A	37.0	28.3
	mixed	N/A	18.5	11.1
	direct	6.3	3.6	8.4
	TOTAL	*6.3*	*7.8*	*11.5*

Table 2: Summary of Results for S2

(2) direct typing, and (3) a mixture of 1 and 2. In the turn count, *other* refers to communication by gesture, vocalization, or no response.

As can be seen in the results summaries, this preliminary study shows that the users benefited from using SchemaTalk. Both the number of words per turn and the overall speech rate saw a definite increase over the course of the study. This is an indication that the quality of turns and the amount of information included in each turn went up as the users became more familiar with the device, taking advantage of its capabilities to access and organize reusable text.

Although the number of turns per interview widely fluctuated, this was probably due to each interviewer's individual style of questioning. Perhaps a better measure to look at would be the proportion of turns involving prestored text. This would reflect the success of the users predicting the types of questions and responses needed for the interview setting. At the very least, the results of this study encourage further testing and development of this method of accessing prestored text.

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Computer Recognition of Dynamic Gestures for Use in Augmentative Communication

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Abstract

The use of gesture-based communication systems by individuals with significant expressive communication difficulties holds promise, but is limited by the need for interpretation by the receiver of the message. The development of a computer recognition technique that accommodates articulation variations and classifies gestures within streams of dynamic data is described.

Background

Gestural communication is believed to precede vocal communication in most individuals. Manual pointing, reaching and grasping movements, eyegaze, and facial expressions appear at early developmental levels (Kinsbourne, 1986).

In some instances, the use of gestures is not replaced by speech, but develops fully into an articulation of language. Among people who are profoundly deaf and are unable to use the auditory channel to reinforce the development of speech, the use of sign language (e.g., American Sign Language) is common.

The use of gesture as a mode of augmentative communication has been discussed in several contexts (Foulds, 1990; Lloyd and Karlan, 1984). The examples below describe two instances where gestural systems are used as alternatives to other augmentative communication techniques.

Example 1. An adolescent male with cerebral palsy has an extensive gesture vocabulary (+150 signs) comprised of conventional ASL signs, modified ASL signs, and gestures of his own invention. The modified signs represent compromises in his precision and range of movement. Handshapes are important in differentiating one sign from another.

His communicative attempts are rich in information. He often accompanies his gestures with facial expression, non-consonantal vocalization, or other body movements such as jumping or stiffening. He does not chain these signs and gestures according to formal syntactic rules (either ASL or English); however, he does "cluster" them when several gestures are needed to elaborate a complex relationship.

Those living with this young man and his classroom teacher understand most of his gestures, while his classmates, classroom aides, and those in the community are unable to interpret most of his gestural expression.

Example 2. A second adolescent male with a rare, progressive neurological disorder, has developed his own gestural language with approximately 30 signs. These are invented gestures and have little similarity to ASL signs. The articulation of the signs is compromised by his motoric disability which limits accuracy, range and speed of movements. Due to physical limitations, only two handshapes (open and closed) are used.

This gestural vocabulary has been promoted by classroom teachers and parents and is used as a primary mode of communication. Since vision is compromised by cataracts, he receives only auditory language feedback, and must rely almost entirely on his proprioceptive feedback for gesture production and refinement.

He uses his gestures individually or in simple combinations, but does not produce syntactically correct sentences. His vocabulary is continuing to expand with the invention of entirely new signs and the combination of existing signs into new signs.

As in the first example, these signs are intelligible only to family members and the classroom teacher.

Statement of the Problem

The two examples introduced above offer both a justification for the use of gestural communication in augmentative communication and an illustration of its primary disadvantage. While both individuals demonstrate reasonable capabilities, their use of their gestural vocabulary and the expansion of that vocabulary are very likely bounded by the exceedingly limited environment in which the gestures are understood. The general problem addressed by this paper is the expansion of that language environment by means of computer recognition of such gestures and their translation into synthesized speech.

Further consideration of the examples defines parameters that are essential to a recognition system. Paramount among these is the broad range of variation that exists across the signs used by the individuals. The two sets of signs described in the examples have few gestures in common.

In contrast to sign languages used by individuals who are deaf, gestural vocabularies used in augmentative communication systems are often idiosyncratic, having been developed in isolation and in accord with the physical abilities of the user. Roy and his colleagues (1994) have shown that many non-speaking individuals are motorically capable of making gestures that are repeatable and can be mapped to words or concepts. Due to the nature of the underlying physical disability, these gestures may not follow any standardized form nor be easily recognized as iconic representations.

A system capable of recognizing gestures must be capable of learning such idiosyncratic gestures and

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cannot be based on a general model of gesture production.

Also evident in the physical production of gestures by both individuals in the examples is the variation in articulation of the same gesture due to the physical disability. The same intended gesture may be altered in accuracy of formation and placement, and may vary in duration. These must be accounted for in a recognition systems.

Additionally, unlike communication systems which are marked with keystrokes, contact of a pen with a surface, or even speech, gestural messages are contained amid a continuous flow of movement of the arms and hands. It is important to identify a meaningful gesture from other non-gesture movements, and separate one gesture from the next.

Approach

Of concern in this paper is the recognition of the arm and head movements which are dynamic in the time domain. Handshape recognition, which is important in an augmentative communication system, is considerably more postural and is addressed elsewhere (Messing, Erenshteyn, Foulds, Galuska, & Stern, 1994).

The approach presented here advances the recognition of arm and head movements in several areas, and overcomes many of the limitations of recognition approaches previously discussed in the literature. As with the previous work, this recognition approach is based on a pattern classification technique that is capable of learning an individual's "style" of movement. Harwin (1991) employed Hidden Markov Models, which are commonly used in speech recognition. Pericos and Jackson (1994) adopted a template matching approach with Dynamic Time Warping, also used extensively in speech recognition. Cairns and Newell (1994) have compared both Dynamic Programming and Hidden Markov Models. Roy et al. (1994) employed back propagation neural networks in their recognition of the trajectory of the arm.

In general, all of the pattern classifiers share common approaches. The positional data, a stream of three-dimensional coordinates varying in time, defines the limb or head trajectory. All of the classifiers use experimental data to derive templates or weights in an attempt to "learn" individual gestures. Subsequent data is compared to what has previously "learned" and best matches are established.

The classification techniques also share common problems. None of the classifiers has been able to deal with the variation in production duration that is common among individuals with significant physical impairment, and none has been able to identify gestures within a continuous flow of movement.

Thus, a gesture that is produced more slowly or more rapidly may appear to the classifiers as very different than the training gestures, even though a human observer may identify these as having the same meaning. Similarly, a human who understands the gestural code may observe a movement and identify the production of meaningful gestures while a computer-based classifier will see only a continuous movement and not identify the beginning and endings of the individual gestures.

As a result, the prior work requires that the stream of gestural data be segmented artificially (by the researchers) for training and test procedures. These projects also seriously limit the variation in duration of a gesture.

The work presented in this paper builds upon the handwriting recognition research of Morasso and colleagues (1993). The recognition of cursive handwriting represents a two dimensional problem similar to the recognition of arm and head movements. The individual letters may vary in duration and size. They are also interconnected within words and are essentially a continuous stream of data points. Individual letters, like individual gestures, are not produced in isolation.

The improvements to the recognition of dynamic gestures include the segmentation of the trajectory according to biomechanical measures. This does not identify the boundaries of individual gestures, but segments the data stream into a series of strokes that are defined by computing the velocity profile of the X, Y, and Z components of the movement. These strokes have been found to be readily and reliably determined.

A gesture, as in Morasso's cursive letters, can be redefined as a combination of strokes. In order to overcome the temporal and size variations, each stroke (which is of course subject to timing and sizing variation) is further processed into a multi-feature vector. This vector characterizes the stroke according to its shape, orientation, and length within the three dimensional space. This allows the length and orientation information to be separated from the shape. (Length may be used in further classification of large vs. small gestures, and orientation may be used to separate the same strokes made in different positions.)

Following the biomechanical segmentation, a committee of unconnected back propagation trained neural networks examines sequences of vectors of successive strokes. Since gestures may be comprised of different numbers of strokes, the parallel neural networks each process different numbers of strokes.

As an illustration, two simple gestures are compared. The first is a circle made with the hand. The second is an up/down movement of the hand. The raw data for each gesture will depend upon its duration, size and orientation.

It is highly likely that subsequent articulations of these gestures could not accurately reproduce their precise trajectories or timing, and would produce very different sets of raw data.

However, when the data are subjected to biomechanical segmentation based upon the velocity profiles, the circle is found to be comprised of four strokes (four arcs that are each in different orientations), and the up/down movement is represented by two strokes (two straight lines each in different orientations). Each stroke is represented by a multi-dimensional vector that accounts for its shape, orientation, and length.

The neural network is trained on the multi-dimensional vectors of known gestures. In the example, there would be a committee of four neural networks that are trained on different numbers of strokes. All vectors are passed by the committee. One network sees the vector of only the current stroke under examination, the second sees that vector as well as the vector of the previous stroke, the third examines the current vector and the two previous vectors, and the fourth see the current vector and the three previous vectors.

Thus, the two stroke up/down gesture will be identified by the two stroke neural network and report a high value for recognition. The other networks that are looking at different number of strokes will report lower values. Similarly, the circle, with four strokes will be identified by the four stroke network.

Implications

The implications of this work are significant in that they make possible the minimization of production variations of timing, accuracy, and orientation. Also possible is the identification of gestures within a data stream, reducing the need for artificial segmentation.

Discussion

The technique presented in this paper offers to improve the ability of computers to classify or recognize arm and head movement that are major components of meaningful gestures. Coupled with ongoing handshape classification, it will be possible to demonstrate a gesture recognition system that can process dynamic movements and classify them into known gestures. Such gestures can then be mapped onto language units (words, phrases, concepts, etc.) that can be spoken through a speech synthesizer.

The ability to transform gestures, which are meaningful but unintelligible to a general audience, into speech will allow users to more fully exploit their gesture capabilities and will likely expand their gesture vocabulary and enhance their communication interactions.

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SIG-04
Drooling

DEVELOPING A DATA BASE FOR A SALIVA CONTROL CLINIC

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ABSTRACT

This paper presents aspects data being collected on nearly 100 clients who attend the saliva control clinic in Melbourne, Australia. The clients range in age from three years to eighteen There are now a number of centres throughout the world who are interested in saliva control and it is suggested a data base be developed which can be accessed by interested researchers. Until recently information has been gathered which fails to define the discrete skills required to develop saliva control. Tools such as the SOMA may assist the collection of detailed data and to further understanding of the complex interacting factors which cause drooling. A call is made to access the current technology to develop data bases and electronically exchange information between countries.

BACKGROUND

In 1986 a saliva control clinic was set up at the Royal Children's Hospital in Melbourne, Australia (1). The idea of a clinic grew from the concerns of a number of professionals who formed a saliva interest grouping 1984 and met regularly to exchange information. It became obvious that adequate saliva control was an important factor in the acceptance of children into community as a whole and in particular integration into the main stream classroom.. There was very little of the specialised knowledge regarding intervention for this problem available in community/hospital settings The formation of the clinic was designed to:-

- bring a team of professionals together to share(and develop) their expertise
- provide a range of professionals in one venue for the parents and carers of these children to ask their questions
- provide assessment of the causes of drooling
- provide details of intervention to the parent and/or a local intervention agency

In retrospect the following aims were also included,to

- provide status to an unpopular area of medicine
- build awareness on intervention to medical practitioners
- monitor clients progress
- make research into assessment and intervention more possible

It is the last aim I wish to pursue, that of developing an international database for research Australia is a large country with a small population. It is the other end of the world for many people and has borne the brunt of jokes for many years. Its' isolation has meant that Australians tend to be very interested in what people are doing in other parts of the world. This interest is infrequently reciprocated. We read with fervour the development of a saliva clinic at the High Macmillan centre in Ontario and with admiration at the Consortium of Drooling (2). In 1992 I visited these developments on a Churchill fellowship and it is because of that visit ,and our continued interest in saliva that I am here today. Australia is no longer isolated, we have telconferencing, video teleconferencing , e mail, the internet. The nineties have given us a way to communicate easily and quickly all round the world. When we are dealing with a specific problem such as drooling which is related to small numbers of people(relatively) then it is in all our best interest to combine in collaborative research to reach our goals. My goal is to better understand the critical skills /components that result in drooling, to identify strategies that can remediate the problem and to better identify appropriate interventions for different groups of clients.I hope this is yours.

APPROACH

Why collaborate ? We have a very incomplete understanding of saliva control. To understand the problem we need input from, neurologists, psychologists, therapists, otolaryngologists, dentists, engineers, statisticians, etc. We make

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decisions as to describe the problem with broad brushstrokes e.g.cerebral palsy or take an impressionistic approach where details are recorded close up but not recognisable until the completion of the study. One of the major drawbacks to our detailed analysis of the problem has been the lack of valid and reliable tools to describe the problem. This is beginning to change. Although the relationship between eating and drinking skills and saliva control is not fully understood, it is generally agreed that there is a relationship. What was spearheaded by Kenny(3) with the multdisciplinary feeding profile has been further developed by Reilly (4) with the Schedule for Oral Motor Assessment .Reilly (4) comments "there were few objective methods of rating oral motor skills and little if any data on important aspects of the functioning of normal children"p177. The SOMA avoids just a broad brushstroke picture but collects information on all levels, the functional area, the unit break down , and the discrete oral behaviours involved. If we are to more fully understand the problem of drooling it will be useful to describe our clients in detail so that we can group them in to more homogeneous groups in order to evaluate the efficacy of treatment

In 1992 on my visits around the world I asked people about the information they were collecting on clients seeking treatment for saliva control . It seemed no-one was already developing a database and so on my return to Australia we continued to collect information we had been collecting since 1991. In three years we have information on nearly 100 clients . But is it the RIGHT information? Why are we collecting information and how will we use it?

Client information is gathered in a number of ways. The major restriction in gathering information is time and clinic appointments may only last twenty minutes. Parent friendly assessments are sent out with the clinic appointment. Where there is a speech pathologist the assessment is completed by the speech pathologist. The results are checked in the clinic and transferred on to a clinic recording form. These are then transferred to a data base at another time. The following information is sought:- child's diagnosis, severity of drooling problem (5) , head posture, open mouth posture, lip competency, ability to use a straw, tongue mobility, ability to chew, awareness of client to saliva on lips/and or chin, sensory status, frequency of swallowing, swallowing pattern, cognition as related to the ability to follow commands related to swallowing/wiping, frequency of food aspiration , presence of asthma, mouth/nose breather, behaviours that might acerbate drooling, presence of epilepsy and medication and dental report. In addition the client is also rated for severity/frequency of drooling which includes number of clothes/bib changes. Computer technology proceeds at a rapid rate. We started loading the information on to Paradox, moved to Excel and are now developing a specific database on Access, a relational database. Many of the software packages are now compatible and once the data has been set up can be easily imported into other packages. Storing information on a spreadsheet such as Excel is fairly simple, however developing the structure for a relational data base is much more complex and requires clear aims for outcomes from the beginning.

RESULTS

The information below relates to data on 85 clients aged between three and eighteen years of age at the initial clinic assessment . Selected fields of data are presented to demonstrate the type of information collected . Full data is not presented on each client.

The clients' diagnoses were as follows:- Intellectual disability(21); other (20); cerebral palsy (16); developmental delay(13); idiopathic (13) ;Down syndrome(2). Eighty of the clients had head control within normal limits, sixty three clients had an habitually open mouth, sixty-seven were mouth breathers and more than half of the clients had difficulty closing their lips adequately. Sixty one clients could easily use a straw. Over half of the clients could eat a wide range of foods without difficulty. Over two thirds of the clients seemed unaware of the saliva on lips and chin and were reported to swallow rarely. These results are the broad brushstrokes that encourage more specific investigation. For instance if two thirds of the clients can drink through a straw it calls into question a commonly reported therapy recommendation of straw drinking to increase the oral motor skills and and assist with the sucking back of saliva. Instead we should be asking what are the requisite skills we are observing and what should we be teaching?.

How do we measure the results of intervention? The measurement of drooling has proved to be a difficult area thought about by many but tackled by few. Methods have included the use of collection units(6)) subjective reporting (5) combination of methods(7) and frequency of drooling by counting (8). In 1991 I completed my Masters thesis investigating the measurement of drooling. Basically I found that bib weighing correlated highly with frequency observation rating (much to my surprise) and as bib weighing is difficult to do in everyday settings we adopted a frequency rating. However the ratings vary considerably during the day and I was unable to find a time sample that adequately represented the full picture of the severity of the child's drooling. Thus now we still include a frequency measure along side a rating scale. I had high hopes with the consortium of drooling recommendations but a non invasive accurate method of measuring drooling still evades us. In clinic we use a scale by consensus. At home and at school we use rating scales and frequency counts. With surgical intervention we add in the number of clothing changes and % improvement by parents.

FUTURE DIRECTIONS

What I propose to ask of the special interest group of RESNA is to develop a data base(or several interlocking ones) which can describe the client, the severity of the problem, and in the longterm predict the likelihood of success of any particular treatment. I would like to see the day when we combine to produce research papers that involve clients from different states, counties and countries (Virginia, Victoria and Ontario!)

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The Prevalence of Sialorrhea in a Population of Children with Cerebral Palsy: Caregiver's Perception

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Children with Cerebral Palsy (CP) often have trouble with saliva overflow or drooling. The prevalence of this problem varies according to definitions of severity, frequency and methods of investigation. We surveyed caregivers of a convenient sample of 768 children seen in an outpatient rehabilitation center to determine the prevalence of drooling for an overall response rate of 62% (n = 476). Sixteen per cent were described as "always" drooling by their caregivers, 48% "sometimes" drooled and 34% "never" drooled. Head position, poor nutritional status, frequent respiratory infections, decreased cognition and verbal skills were associated with drooling. Caregivers desired changes in their child's problem with saliva overflow.

Background

Between 10 and 37% of children with CP lose saliva from their mouths or drool (Harris & Purdy, 1987). Drooling interferes with social, academic and day to day functioning and in inconvenient to both children and caregivers (Blasco, Allaire, et al., 1992). The prevalence of drooling is a consideration for clinicians determining interventions for the amelioration of drooling and investigating the problem. In order to determine the prevalence of drooling in a pediatric population of children with cerebral palsy, we surveyed their caregivers. The caregivers of children registered in the outpatient clinic of a pediatric/orthopedic outpatient clinic comprised the study population.

Research Questions

1. What is the prevalence of drooling in children with developmental disabilities?
2. What are the characteristics of these children?
3. What are the associated difficulties with drooling?

Methods

We developed a survey based on forced choice questions in the following areas: prevalence and severity of drooling, oral motor skill, head and body position, and attitudes about drooling. The survey was piloted via telephone on a sample of caregivers. Following revisions, two research assistants were trained on the administration of the survey. The survey was mailed to those families who could not be reached by phone. Because drooling is not felt to be clinically significant until after 4 years of age, children younger than 4 were omitted from the database. The data was analyzed on an Austin 386*25VL desktop computer using Paradox 3.5 software package.

The clinic cares for 768 children with CP. Three hundred five (305) were surveyed by phone. Those unavailable by phone received the same survey by mail. Of this group, 171 returned mail surveys. This resulted in an overall response rate of 62%. Chart reviews were performed to determine the childrens' types of CP.

Results

Sixteen percent of subjects were described as "always" drooling by their caregivers (A-group), 48% "sometimes" drooled (S-group) and 34% never drooled (N-group). Children with spastic quadriplegia were the most likely to drool (31% A-group and 52% S-group) with mixed (20% and 58% and extrapyramidal (17% and 60%) being the next highest in caregiver's perception of prevalence of drooling. Sialorrhea was reported as fairly common in spastic hemiplegia (6% and 39%) and spastic diplegia (8% and 25%). Using a 2x2 contingency tables, abnormal head position, poor nutritional status, frequent respiratory infections, decreased cognition and verbal skills were also found to be associated with drooling. Eighty-six percent of the A-group caregivers and 51% of the S-group caregivers reported they wished to improve their child's problem with drooling.

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[1] Dr. Pelegano is currently associated with the Hospital for Special Care, New Britain, Connecticut.

Table 1

Prevalence of Drooling (N = 386)*

	N	%
Always Drool	63	16
Sometimes Drool	186	48
Never Drool	132	34
No response	5	2

*Omits children under 4 years

Table 2

Drooling by Type of CP

		%who drool	
	Always	Sometimes	Never
Spas Quad	31	52	17
Spas Di	8	26	66
Spas Hemi	6	39	55
Mixed	20	58	22
Athetoid	17	60	23

Discussion

Drooling is reported by caregivers in children with CP by severity and frequency. Sixteen percent of subjects were described as "always" drooling by their caretakers. Children with spastic quadriplegia were most likely to drool. Drooling may be more common than previously suspected. It is more likely to occur in conjunction with abnormal head position, poor nutritional status, frequent respiratory infections and decreased cognition and verbal skill. The clear majority of caregivers (86%) expressed the desire change or improve their child's drooling.

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SIG-05
Quantitative Functional Assessment

COMPARISON OF OXYGEN UPTAKE AND PHYSIOLOGIC COST INDEX (PCI) AT SUBMAXIMAL WALKING VELOCITIES

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ABSTRACT

The purpose of this project was to compare the inter-day reliability and effect of varying walking velocity on two measures of overall gait performance; oxygen uptake rate (VO_2) and the physiologic cost index (PCI). Thirteen healthy subjects (6 male, 7 female) walked on a treadmill at four randomly ordered, submaximal walking velocities (3.0, 3.7, 4.4, and 5.1 mph) for approximately five minutes at each speed. At steady state, VO_2, heart rate (HR), and PCI were recorded from each subject at all four speeds. The identical experiment was repeated approximately one week later, to determine inter-day reliability. Intraclass correlation coefficients ($ICC_{1,1}$) were calculated for inter-day observations of VO_2, HR, and PCI, grouping all speeds and all subjects ($n = 52$). Linear regression was used to determine the relationship between the three dependent variables (VO_2, HR, and PCI) and walking velocity. The results indicated that VO_2 and HR are more reliable than PCI for observations taken several days apart, primarily because of the need to obtain accurate resting heart rates when calculating PCI. However, PCI does demonstrate the same trend as VO_2 and HR; all three increase with increasing walking velocity.

BACKGROUND

When attempting to characterize an individual's ability to walk, it is helpful to measure some quantity that can be used as an index of overall gait performance. Having such an index can be useful for determining the merits of a therapy or conditioning program targeted to improve a subject's gait. One good candidate for this index is to record oxygen uptake (VO_2) during walking. Conventional methods for obtaining VO_2 recordings on a breath-by-breath basis during gait usually require treadmill ambulation, and a face mask or mouth piece connected to a stationary instrument to capture and analyze the expired gases. Such methods are unreasonable or unavailable in many clinical environments, especially if the goal is to obtain an easily acquired index of overall gait performance rather than to quantify the cardiovascular system. Furthermore, the physical restrictions imposed by the measurement equipment may interfere with the subject's normal walking pattern, especially for handicapped individuals who often rely more heavily on visual input to substitute for reduced proprioception and kinesthesia. A more practical index would show a similar response to changes in workload as oxygen uptake, but be obtainable without the cumbersome and potentially disruptive data collection methods common to VO_2.

While ambulatory recordings of average heart rate (HR) are easy to obtain and correlate well with VO_2 at submaximal work intensities (1), use of HR as a gait performance index may not be ideal. This is because HR by itself does not include any functional measure describing the ability of the subject to accomplish the primary goal of walking; to efficiently move the body forward. The Physiologic Cost Index (PCI), first introduced by MacGregor (2), is the ratio of heart rate increase above resting to walking velocity. Algebraically,

$$PCI = \frac{HR_{walking} - HR_{resting}}{\text{average walking velocity}}$$

in units of beats/meter. PCI may be useful as a measure of overall gait performance, since it combines a physiologic measurement (HR), with a functional measure of gait (average walking velocity) in a single, easily obtainable index. It has been used clinically to evaluate the gait performance of children with cerebral palsy (3), elderly subjects enrolled in a walking program (4), and paraplegics using the ORLAU ParaWalker (5) and functional electrical stimulation (6). However, no study has compared PCI to VO_2 prospectively in the same subjects.

RESEARCH QUESTION

This project was designed to substantiate the use of PCI as an index of overall gait performance, by comparing PCI to VO_2 in terms of inter-day reliability and each measure's relationship to changes in walking velocity. If PCI was found to be equally reliable and displayed a similar relationship as VO_2, this would support the continued use of the index in clinical environments where the use of traditional gas collection apparatus was impractical.

METHODS

Subjects: Thirteen healthy adult subjects (6 male, mean age 27.3 years, 7 female, mean age 30.0 years) without history of previous gait pathology volunteered for the study. Any individuals with significant health problems or a history of orthopedic, cardiovascular, or pulmonary dysfunction were excluded from the study. All subjects read and signed an informed consent form approved by the Institutional Review Board of the University of Texas Southwestern Medical Center prior to beginning the study.

Experimental Procedure: Each subject reported to the laboratory wearing comfortable workout clothing and running shoes. Disposable ECG surface electrodes were applied in a lead II configuration over the mid clavicular region bilaterally, and close to the left 7th intercostal space. These were connected to a Hewlett Packard model 78101 ECG telemetry system, whose receiver was connected via a signal conditioner to one of two counters on a National Instruments data acquisition board in a 286 class PC. After affixing a mouthpiece and nose clip to the subject for expired air collection, resting HR was recorded while the subject was quietly standing on the Pacer motorized treadmill used for the experiment. After allowing a brief warmup period, the treadmill was set to the first of four speeds (3.0, 3.7, 4.4, and 5.1 mph) selected in random order. Each subject walked or ran at the selected speed for a period of approximately five minutes, while continuously recording HR and expired gases breath-by-breath. Gases were collected using a Perkin Elmer model MGA-1100 mass spectrometer and ventilation rate was recorded using a Sensormedics VMM. Both devices were synchronized and recorded in real time using a custom hardware/software interface running on the same PC used for HR recording. Thirty second averages of HR, VO_2, and PCI were obtained at two and five minutes into the selected speed. If the five minute sample was within ±5% of the two minute sample, it was assumed that steady state had been achieved, and the five minute recording was used for analysis. If not, additional 30 second averages were obtained until this criteria was met, at which point the treadmill speed was changed immediately to the new speed. This was repeated until all four speeds were tested, and the entire procedure was repeated approximately one week later.

Data Analysis: PCI, VO_2, and HR data from all subjects were compiled in an Excel™ spreadsheet on a Macintosh computer. The absolute (non-normalized) values were exported to another program for calculation of intra-class correlation coefficients ($ICC_{1,1}$ - n = 52) for determining inter-day reliability of the three dependent variables. Normalized data were calculated by dividing each subject's steady state values by that individual's maximum value obtained over the four speeds for that testing day. These data were then exported into IGOR™ analysis software where least square linear regressions were calculated using all subjects at all speeds on both days (n = 104). Normalizing data prior to regression permitted direct comparison of the resulting curves.

RESULTS

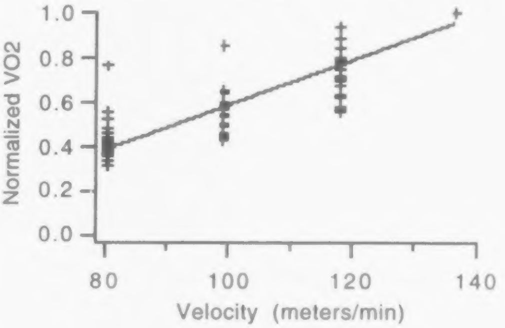
The results of the inter-day reliability analysis using $ICC_{1,1}$ are shown in Table 1.

Table 1: Inter-day Reliability Results

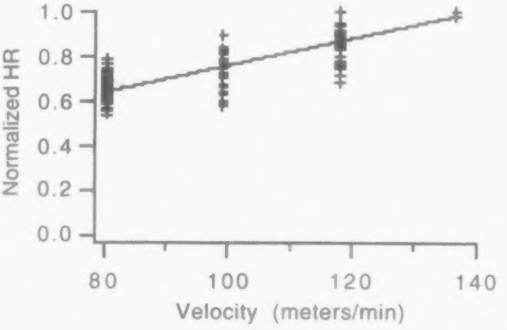
	VO_2	HR	PCI
n	50	52	52
$ICC_{1,1}$	0.885	0.789	0.292

The results for the regression analysis of VO_2, HR, and PCI are shown in Graphs 1, 2, and 3 respectively.

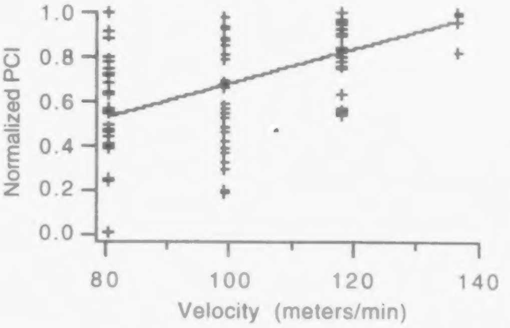
Graph 1: Normalized VO_2 vs. Velocity



Graph 2: Normalized HR vs. Velocity



Graph 3: Normalized PCI vs. Velocity



All ICC's were calculated using both observations at each speed for all subjects. VO_2 data had an n = 50 because the results for the two intermediate speeds on the second trial for one subject were lost due to a mass spectrometer failure. Despite this, the inter-day reliability was the highest among the three measures.

The linear regression graphs include the individual data points that were used to calculate the regression lines shown. The Pearson's linear correlation coefficients (r) for each of the graphs are compiled in Table 2.

Table 2: Correlation Coefficients for Regressions

	VO_2	HR	PCI
r	0.919	0.876	0.663

DISCUSSION

Increasing numbers of clinical investigators are turning to PCI as a simple outcome measure that can describe the gait performance of their patients when other methods, such as oxygen uptake, are deemed inappropriate. By combining a physiologic measure (HR) with a fundamental gait performance measure (average walking velocity), PCI has the potential to satisfy this need. However, any measure considered as a replacement for traditional VO_2 recording must not only demonstrate a similar relationship, but must also possess similar reliability. In this experiment, PCI met only the first criteria.

Insight into why the inter-day reliability of PCI is considerably less than VO_2 can be obtained by considering the other variables comprising the PCI equation. Since the reliability of HR alone approaches the reliability of VO_2 (0.789 vs. 0.885), and the walking velocities were fixed, the resting HR recorded at the beginning of each day must have a major influence on the reliability of PCI. In this experiment, resting HR was obtained while the subject was standing on the treadmill, with all expired gas collection devices attached. While this is desirable from the standpoint that the resulting increase in HR seen during the experiment is completely due to the gait task performed, it was apparent that there was a wide variation in the subject's ability to control their HR prior to testing. Some subjects were able to lower their HR substantially on command, while others seemed more anxious, resulting in a temporarily elevated HR. In addition, outside factors such as caffeine level and time of day were not strictly controlled, which may have lead to inaccurate recordings during the resting HR period. While it is clear the reduced inter-day reliability of PCI cannot be completely explained by variations in the resting HR, we feel that great care must be taken when recording this reference if PCI is to be used in the clinic.

Despite this lower than expected inter-day reliability, the regression analysis illustrates that the relationship between PCI and velocity mimics the VO_2 and HR graphs; increased workload yields an increased PCI. While definitely not as good a fit as either VO_2 or HR (r = 0.663 vs 0.919 and 0.876 respectively), it appears that with enough samples PCI may prove satisfactory in those situations where more robust procedures are unavailable.

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A SYSTEM TO EVALUATE PARALYZED LOWER-LIMB MUSCLE PERFORMANCE DURING FES-INDUCED CONTRACTIONS

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ABSTRACT

A muscle performance evaluation system for use on lower-limb paralyzed muscles was developed utilizing a Kin-Com isokinetic dynamometer, microcomputer, data acquisition software, and a custom-designed electrical stimulation unit. To test the validity of this system, individuals with SCI underwent isometric testing of the quadriceps, hamstring, gluteal, anterior tibialis and gastroc-soleus muscle groups. The protocol consisted of 20 FES-induced isometric contractions, each followed by a 5-sec rest interval. For each contraction, FES current was ramped from 0-300-0 mA in 24 sec. Results obtained from this evaluation system generally showed that as fatigue progressed, contraction threshold increased, maximum force decreased, the slope of the force/current curve decreased, and force-current hysteresis increased. Occurrence of spasms and antagonistic muscle co-contractions were also determined. Data suggest that this standardized system can provide detailed information about individual muscle performance characteristics, which may be useful in designing and evaluating FES-assisted technologies.

BACKGROUND AND PURPOSE

Therapeutic FES-induced exercise of paralyzed lower-limb muscles is being used in an effort to improve the health status, physical fitness, and rehabilitation potential of individuals with SCI and various other neuromuscular disorders (1,2). Muscles employed for various clinical FES modalities include the quadriceps, hamstring, gluteal, gastroc-soleus, and tibialis anterior. Of course, to obtain a desirable muscle contraction pattern a proper application of FES current is required. However, performance characteristics among the various muscles employed can be quite different with respect to fiber recruitment pattern, maximal force output and fatigability. Thus, each muscle has its own particular FES current operating range for suitable function. Furthermore, the ratio between force developed and FES current decreases at a certain rate as fatigue progresses (3), depending upon the particular muscle and its state of conditioning. Spasms and antagonistic muscle co-contractions can also affect performance. Therefore, it would be desirable to objectively evaluate the contraction characteristics of various lower-limb muscles to determine their particular FES current operating range, and to ascertain how contraction characteristics change with progressive fatigue, as well as during therapeutic exercise conditioning programs. Thus far, however, the literature contains only few descriptions of techniques for objective FES muscle evaluation, and little data concerning the FES-induced contraction characteristics of various lower-limb muscles (3-8).

The purpose of this study was to develop and test a standardized system to objectively evaluate the FES muscle performance (i.e., operating current range, recruitment pattern, and fatigability) of the major lower-body muscle groups during repetitive contractions of ramped intensities. This system can provide information regarding the specific: 1- current threshold for contraction; 2- current to elicit peak force; 3- force developed per unit of stimulation current; 4- spasms and antagonistic muscle co-contractions elicited; and 5- changes in muscle performance during progressive fatigue.

METHODS

Instrumentation. The basis of the FES muscle performance evaluation system is a Kin-Com II isokinetic dynamometer used in conjunction with a specially designed and constructed selectable parameter stimulator. Fig. 1 provides a block diagram of the evaluation system. The stimulator allows for pre-setting of: max current output from 0-300 mA; pulse frequencies from 10-100 Hz; pulse durations from 50-600 μs; and, balanced monophasic or biphasic rectangular, sine, or triangular waveforms. Adjustments are also available for setting threshold current, current ramp rate, the number of contractions induced, rest interval, and the force limit. The FES current and contraction force data are fed into an analog-to-digital converter in the microcomputer which utilizes Asyst data acquisition/analysis software. Data are also displayed in real time on an X-Y plotter.

Preliminary Testing. Subjects with lower-limb paralysis due to SCI were used to test the Kin-Com FES muscle performance evaluation system. The protocol and procedures followed were approved by the IRB of our institution. An informed consent form was signed by the subjects prior to participation. For this paper, only illustrative examples of the data obtained are presented to demonstrate operation of the instrumentation.

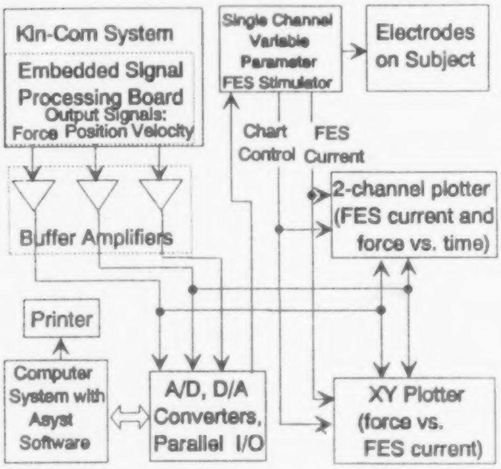
Kin-Com System
Embedded Signal Processing Board
Output Signals:
Force Position Velocity
Single Channel Variable Parameter FES Stimulator
Electrodes on Subject
Chart Control
FES Current
2-channel plotter (FES current and force vs. time)
Buffer Amplifiers
Printer
Computer System with Asyst Software
A/D, D/A Converters, Parallel I/O
XY Plotter (force vs. FES current)

Fig. 1. Block diagram of the Kin-Com FES muscle performance evaluation system.

Protocol. Bipolar surface electrodes were placed over the motor points of the muscle group being tested. Body position and Kin-Com adjustments were made to insure proper joint positioning. The stimulator was set to biphasic rectangular wave pulses that were 300 μs in duration at a frequency of 35 Hz and a max current of 300 mA. Twenty FES-induced contractions were performed with a linear ramped increase in current from 0-300 mA in 12 sec, followed by an identical ramped decrease in current from 300-0 mA. Rest intervals between contractions were set to 5 s. Stimulation intensity was permitted to ramp upward so long as force remained less than 150 N. However, if 150 N was reached, stimulation current was automatically reversed to reduce force. This maximal force limit was set as a safety precaution to prevent injury.

RESULTS AND DISCUSSION

A representative example of the FES current-contraction force data with respect to time obtained during the 1st, 5th, 10th, 15th and 20th contraction (shown for clarity) of the quadriceps muscle of a subject with quadriplegia is illustrated in Fig. 2. The 150 N force limit was achieved for the first 10 contractions. Then, force progressively decreased with fatigue since the 300 mA current limit was reached and there was no additional fiber recruitment. The threshold current was about 50-60 mA and approximately 250 mA was required for full fiber recruitment for this particular muscle.

Fig. 3 illustrates the current vs force data for the same muscle in Fig. 2, but without regard to time. The 150 N force limit was achieved on the 1st contraction at about 150 mA. In contrast, this force production required about 175 mA on the 5th and 250 mA on the 10th contraction. On the 15th and 20th contractions, force markedly decreased despite the 300 mA current application. In addition, force-current hysteresis tended to increase with fatigue, and it took less current to maintain a given contraction force, once achieved.

Fig. 4 illustrates the ratio between FES current and contraction force for the same quadriceps muscle in Figs. 2 and 3 for each of the 20 repetitive contractions. The slope of this line provides indices of the muscle's responsiveness to FES, as well as of its fatigability for FES-induced contractions.

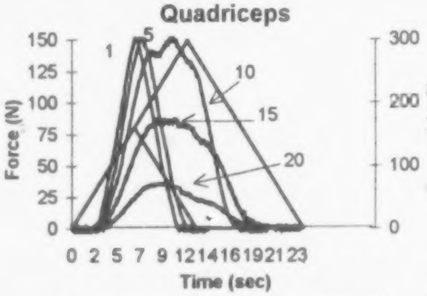

Fig. 2. Composite FES current-contraction force data with respect to time for the quadriceps muscle.

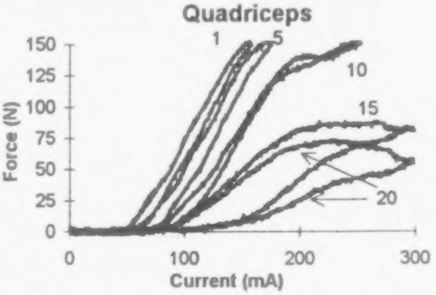

Fig. 3. FES current vs force produced relationship for the same quadriceps muscle in Fig. 2.

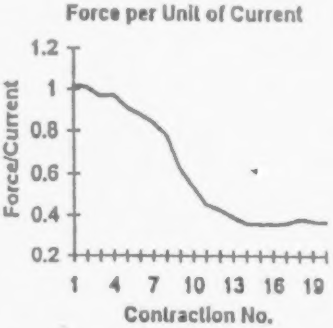

Fig. 4. The ratio between contraction force vs FES current for 20 repetitive contractions of the same quadriceps muscle in Fig. 2.

To illustrate the occurrence of spasms elicited by FES sensory effects, Fig. 5 represents the FES current vs contraction force relationship for the gastroc-soleus muscle group. A spasm causes the loss of contraction smoothness as shown on the 1st contraction.

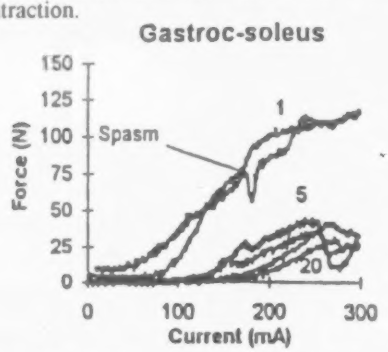

Fig. 5. The FES current vs contraction force for the gastroc-soleus muscle group showing a spasm that occurred on the 1st contraction.

To illustrate the occurrence of antagonistic muscle co-contractions, Fig. 6 represents the FES current vs contraction force relationship for the anterior tibialis muscle. As contraction threshold is exceeded, the force began to rise in a positive fashion. However, as FES current increased to a certain level, co-contractions of the antagonist (gastroc-soleus) muscles become stronger than the agonist (anterior tibialis) muscle. This can be seen by the negative force readings that follow the positive force readings. The less negative force readings that occurred during the 5th to 20th contractions may indicate progressive fatigue of the gastroc-soleus muscle group.

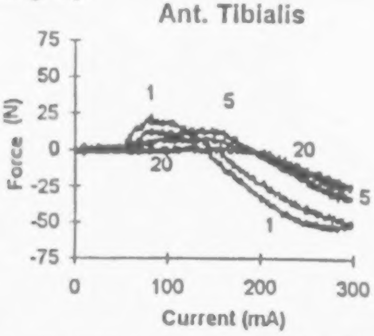

Fig. 6. The FES current vs contraction force for the anterior tibialis muscle. Co-contractions of the antagonistic gastroc-soleus muscle group are indicated by the negative force readings.

Conclusion. The described FES muscle performance measurement system appears to provide a valid, reliable, and objective technique to standardize evaluation of contraction characteristics for lower-limb paralyzed muscles. Information derived can also be useful for evaluating exercise training adaptations, as well as for developing computer algorithms for more precise FES control of paralyzed lower-limb muscles.

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ACCELEROMETRIC MOTION ANALYSIS OF BALANCE-IMPAIRED ELDERLY SUBJECTS

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ABSTRACT

We have previously reported studies on upper body motion analysis using a wearable accelerometric data acquisition system. Our studies have expanded to include data collection from subjects diagnosed with Parkinson's disease, post-stroke hemiplegia, hip arthroplasty, and fall-prone elderly.. This paper examines the use of accelerometry in quantitative analysis of balance-impaired elderly subjects. In particular, the activities of sit-to-stand and quiet standing are used to present apparent differences between normal and balance-impaired subjects in accelerometric data. collected.

BACKGROUND

Falling is a prevalent problem in the elderly population. The sense of balance declines with age due to combined vestibular, proprioceptive and visual losses, resulting in impaired mobility and increased risk of injurious falls. According to Rubenstein, et.al [1] approximately one third of the elderly population living at home will fall each year. About one in forty of these falls will result in hospitalization of the elderly individuals. It has also been reported that recent prior experience of a fall results in fear of falling which has been associated with a significant decrease in social and daily activity and, therefore, quality of life [2, 3].

The physical stability of "balance-impaired" elderly populations (i.e., those diagnosed with Parkinson's disease, post-stoke hemiplegia, hip arthroplasty) is further challenged as compared with normal elderly populations.

Previously, we have reported findings on the use of accelerometry as a measure of stability in the elderly and were able to present distinguishable differences between elderly and young populations [4]. In this paper, we will examine the use of accelerometry as a means of quantitative analysis of elderly balance-impaired subjects.

METHODOLOGY

We have tested subjects as they performed 65 standardized activities, including standing, reaching, bending and walking tasks and simulated activities of daily living (ADLs). The baseline healthy subject pool consisted of 18 elderly (59 to 82 years, equal number males and females) and 12 young (19 to 37 years, 8 male and 4 female). Balance-impaired subject groups included Parkinson's disease patients (20 subjects), pre- and post-surgery hip prosthesis patients (20 subjects), stroke patients (4 subjects) and fall-prone participants in a study of physical therapy to reduce fall risk (17 subjects).

A self report questionnaire, was used to document the characteristics of the subjects and to determine eligibility. Data included fall history, medical history, medication, and the Physical Self-Maintenance Scale [5], which assesses need for help with feeding, dressing, grooming, ambulation, and bathing.

Two 3-axis accelerometers were attached to the left and right corners of eyeglass frames for measuring head motion. Each sensor assembly with its cable weighs 28 grams. Another pair of 3-axis accelerometers were attached to a Velcro belt at the waist above the hip joints to detect body motion. The twelve accelerometer signals were fed to a small (5 x 8 x 15.5 cm) portable computer with battery power source, also attached to the belt. The whole system weighs slightly under 1 kg with the weight equally distributed between front and back of the belt. Technical details of the system were reported previously [6].

Each 3-axis accelerometer site yielded **Z** (vertical), **X** (antero-posterior), and **Y** (lateral) signals. After calibration for individual sensor characteristics and conversion to units of gravity ($1\ \mathbf{g} = 9.8\ \mathrm{m/sec}^2$), two calculations were performed: (1) The acceleration magnitude irrespective of direction of movement was determined by taking the vector sum of the **X**, **Y** and **Z** axes at a single sensor site; this value was expressed in units of gravity and normalized to eliminate the constant 1 **g** gravitational acceleration. (2) lateral sway, $\angle \mathbf{ZY}$, angles of the trunk and head relative to vertical were derived from the vector sum of the **Z** and, **Y** accelerometric signals such that $\angle \mathbf{ZY} = \arctan(\mathbf{a}_Z/\mathbf{a}_Y)$. The standard deviation (SD) of tilt angle $\angle \mathbf{ZY}$, which represents the root-mean-square difference from the mean over the duration of the task, was used as the measure of steadiness. Sway stability has been reported as a predictive measure of fall risk in elderly populations [7]. To eliminate artifacts at the start and end of a task and highly variable events such as false starts and stumbles, the lowest standard deviation (SD) at all four sensor sites during a contiguous 3 second interval was used. This concurrent minimum SD includes a subject's best performance even if he or she had episodes of greater unsteadiness at other times during the test, and therefore is a conservative measure for comparison between groups having varying balance stability. The 3-second interval was selected after observing that even in short (5 second) tasks, overt loss-of-balance episodes lasted no more than two seconds.

RESULTS

Currently, data from one stroke (62 year old female) and four pre-surgery hip-replacement (3 male, ages 59, 60 and 70; 1 66 year old female) subjects have been examined. Results from sit-to-stand and quiet standing activities will be discussed here as an example of analyzing a static and dynamic activity.

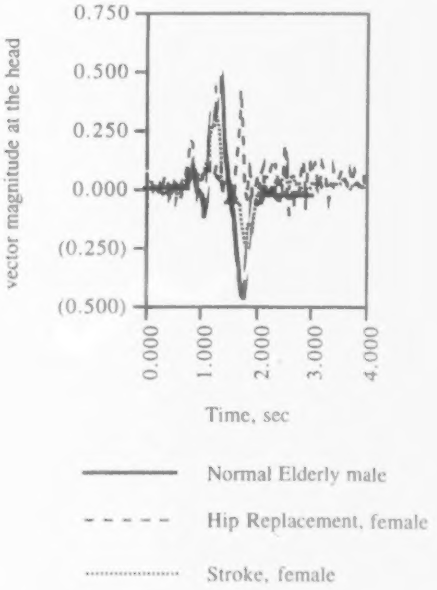

Figure 1. Vector magnitudes derived from accelerometric data during sit-to-stand performed by normal and impaired subjects.

Sit-To-Stand

According to Schenkman, et.al. [8], there are typically four stages evident in performance of a "normal" sit-to-stand. They are as follows: (1.) flexion momentum = initiation of movement to just before buttocks are lifted from the seat; (2.) momentum transfer = buttocks lift from the seat to maximum ankle dorsiflexion; (3.) extension = just after maximal ankle dorsiflexion to when the hips first cease to extend; (4.) stabilization = just after hip-extension to when all motion associated with stabilization from rising is complete.

In Figure 1, the plot of the vector magnitude at the head of three subjects performing a sit-to-stand are superimposed. The normal elderly male's trace depicts all four stages, as expected. Stage 1 begins at the beginning of motion to the inflection point of the second positive peak as the head accelerates forward. Momentum transfer ends at the bottom of the negative peak as the subject's center of mass travels anteriorly and upward. Extension ends and stabilization begins after the rise of the negative peak.

The female stroke subject's trace is similar to the normal elderly male's trace in form. Each of the significant peaks are present, except with less amplitude and more frequent fluctuations throughout the activity. The settling period also extends further than that for the normal subject. This subject has left hemiparesis. She has also been diagnosed with diabetes, high blood pressure, and arthritis. She indicated that she has required some assistance in performing activities of daily living, but is relatively independent and ambulatory with a cane. This subject was able to perform the sit-to-stand shown in Figure 1 without assistance.

In the sit-to-stand trace of the female hip replacement subject, the normal significant peaks are not apparent. And, even more erratic fluctuations throughout the trace are present. This subject required a right hip replacement due to degenerative arthritis. She indicated feeling a great deal of pain during testing.

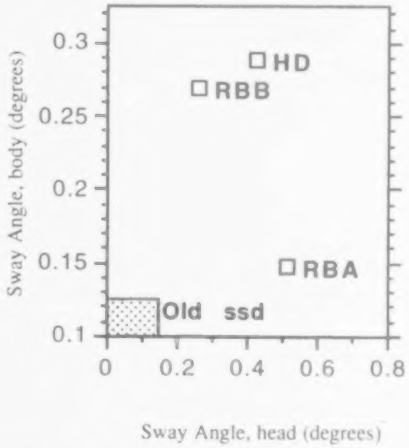

Figure 2. Sway angle at the head vs. sway angle at the hip of normal elderly and hip replacement patients during quiet standing.

Quiet Standing

The best three second standard deviations of the sway angles ($\angle \mathbf{ZY}$) at the head were plotted against standard deviations at the body for three male hip arthroplasty subjects tested during quiet standing before surgery (Fig. 2). We would expect to find subjects with greater sway at the head and at the body than normal elders (the shaded box), represents normal baseline elderly sway ranges (head=0.110 degrees; body=0.119 degrees). All three subjects remained outside of the normal elderly sway range.

DISCUSSION

The goal of this paper was to examine the use of accelerometry for the analysis of balance-impaired elderly subjects. We were able to identify abnormal sit-to-stand body motions (i.e., increased frequency of fluctuations and increased settling time) which may be indicative of decreased steadiness. We were also able to identify excessive sway during quiet standing outside of "normal" limits based on our normal elderly baseline population. In general, the existence of balance impairments were distinguishable in accelerometric data of both sit-to-stand and quiet standing activities. We plan to continue data collection and analysis on these impaired populations in an effort to study the subtle balance effects of different disorders and to quantify the changes in balance as a patient's condition improves or worsens.

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MATHEMATICAL MODELING AND OPTIMIZATION:

Demonstrating Changes in the Tone of those with Cerebral Palsy

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ABSTRACT

This paper is a follow-up to one written for RESNA several years ago. The author proposed that mathematical modeling could offer insights into changes in muscle tone resulting from a form of vestibular stimulation. This paper presents progress the author has made in that direction. A model of a test to measure spasticity (the Leg Drop Pendulum Test) is outlined. The process by which the model is optimized to fit three subject's data is presented. Force inputs required for an optimized solution are compared in a set of triplet subjects (one triplet is without disability, the other two are diagnosed with spastic diplegic cerebral palsy). These forces demonstrate the higher excitability of muscle stretch receptors in cerebral palsy as well as a reduction in excitability after stimulation via whole body vertical oscillations.

BACKGROUND

Cerebral palsy is a nonspecific term used to describe a persistent qualitative motor disorder caused by nonprogressive damage to the central nervous system[5].

Mathematical modeling of neuromuscular systems is used to provide insight into how various levels of the nervous system might function. The purpose of this paper is to provide a follow-up to work the author advocated for in a previous RESNA paper[1]. In particular, it was suggested that much can be gained from the application of systems modeling to various phenomena observed in the cerebral palsy clinic which are, at present, poorly understood. One phenomenon, which is the basis for the present work, is the effect of whole body vertical acceleration, a form of vestibular stimulation on those with cerebral palsy. Therapy programs often utilize a form of slow, rhythmical vestibular stimulation in order to inhibit abnormally high muscle tone[3].

If researchers and clinician alike are to make optimal use of vestibular stimulation for normalization of muscle tone, there must be a complete understanding of both the physiological mechanisms by which the desired change in tone is effected and the means by which the effect can be maximized.

As an illustration of the kinds of insights that can be gained from modeling efforts, work will be presented on a model of the Leg Drop Pendulum Test[4]. This test is commonly used to assess spasticity. In the case presented here, the author uses the test to evaluate changes in spasticity following whole body vertical oscillations. The author and his coworkers have demonstrated that whole body vertical accelerations have a positive effect in decreasing some measures of spasticity in a small population with this disorder[2][6]. A set of triplets were among the subjects studied. Two of these three subjects had varying degrees of spasticity and one was without a disability. The triplets afforded an excellent opportunity to study the differences and similarities using modeling techniques.

This paper will demonstrate that by building a model of the limb of both the normal subject, and the subject with cerebral palsy, and by comparing model parameters from each, a greater understanding of the differences between each can be achieved. Furthermore by studying these parameters in both the before and after stimulation models of the subjects with cerebral palsy, insights into the changes in limb function can be better understood.

An approach will be adapted similar to Ramos and Stark[7] in that it will deal with the spinal level joint angle control system. For the present investigation all input to the muscles, either from higher centers of the nervous system or from feedback circuitry will be lumped into one or more force inputs. These force inputs represent final common pathway excitation of the muscle.

RESEARCH QUESTION

How might modern systems modeling be used to enhance the understanding of the effect of whole body vertical oscillations on the overall tone of those with spastic cerebral palsy?

METHOD

The model described in this paper will consist of a "passive plant" which represents the anatomy and physiology of the knee, acted on by a set of forces which represent the contractions of muscle groups about the knee. The Passive Plant, and the Active Forces can both be represented by an equation of motion.

This equation, stated simply, says that when a limb is dropped in a Leg Drop Pendulum Test, the acceleration, velocity and position changes it experiences are caused by a muscle force "F" and a gravity force "G" (see figure 1). For every pattern of motion that a limb might fall through, during the test, there is a unique set of values for all the parameters (symbols) in the equation below. Since the motion of the limb can be known (by recording limb motion with a video camera for example) a set of parameters can be found which makes the above equation represent that motion. This process, of finding parameters that makes the equation fit the real motion, is described as optimizing the equation on the real data.

$$F = J\ddot{\theta} + B\dot{\theta} + K\theta + KP_1(e^{KP_2\theta} - 1) + C - G$$

$$C = \begin{cases} C_e(\theta \geq 0) \\ C_f(\theta < 0) \end{cases} \quad K = \begin{cases} K_e(\theta \geq 0) \\ K_f(\theta < 0) \end{cases}$$

$$B = \begin{cases} B_e(\theta \geq 0) \\ B_f(\theta < 0) \end{cases} KP_x = \begin{cases} KP_{ex}(\theta \geq 0) \\ KP_{fx}(\theta < 0) \end{cases} \qquad (1)$$

Where: G = Force due to gravity C = Coulomb friction
e = extension f = flexion
F = Muscle Forces

Figure 1
Equation of Motion

The above equation of motion has been optimized on the real data of three subjects under two conditions. The three subjects were unique, they were triplets. This is special because it allows many of the parameters in the equation of motion to be the same for all three subjects. For example, since the height and weight of all three are the same, the force of gravity "G" is the same as is the inertia "J" of the lower leg. Since it is assumed that all three anatomies are the same, spring "K", "KP", damper "B" and coulomb friction "C" parameters can all be set to the same respective values for the three subjects. The only differences then, across the three models, and the two conditions (stimulated or not) are the muscle forces.

The optimization problem is now much simpler. The Passive Plant parameters ("K", "KP", "B", "C" and "G") need be found only once and used for all three subjects. In doing so the data collected from the subject without disability was used. This was done because it was expected that his/her force input would be a minimum. Instructions to the subjects before the test were to relax the limb completely; the subject without disability found it easiest to comply.

Once the anatomically dependent Passive Plant parameters have been identified the remaining task is to identify the force input required to match model data to real data. By examining these forces one can see the differences in patterns of contractions for the three subjects both before and after stimulation.

RESULTS

Figure 2. below illustrates forces which are generated in a normal limb during a Leg Drop Pendulum Test. It can be assumed that there is some activity in the muscle due to the stretch reflex, however on the whole, the muscle is at rest. This figure should be compared to the next which illustrates forces optimized for the model of one of the triplets with cerebral palsy. The differences in forces needed to generate this model data are obvious, almost 14 times as much force is generated in this model than the last. This illustrates a highly sensitive reaction to the muscle stretch which accompanies the leg drop. This result is certainly consistent with present knowledge of the stretch reflex, which would be expected to be more sensitive in those with cerebral palsy.

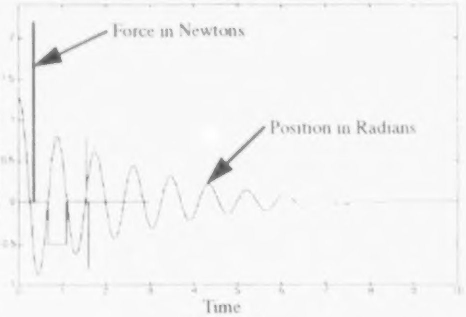

Figure 2
Timing and Amplitude of active Forces-
Normal Model

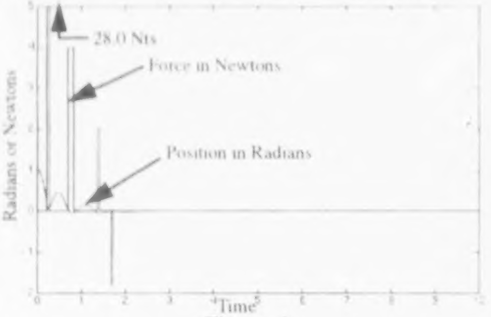

Figure 3
Timing and Amplitude of Active Forces
Spastic Model--Before Stimulation

Finally, Figure 4 below illustrates forces generated for a model of the same subject's position data after whole body stimulation. Differences here are seen in the amplitude and directions of the forces. The drastic reduction in force by four fold, 28.0 to 7.0 Nwtns, clearly suggests that the excitability of this muscle is reduced. Changes in direction of force indicate that agonist as opposed to antagonist muscles must be activated in order to recreate the real data using the model.

Table 1: Force Amplitudes and Durations

Subject	Physical Status	Fe_1 Amplitude Duration	Fe_2 Amplitude Duration	Ff_1 Amplitude Duration	Ff_2 Amplitude Duration
DC	Non-Disabled	2.30 Nt. 0.03 sec.	0.81 Nt. 0.01 sec.	0.49 Nt. 0.42 sec.	0.82 Nt. 0.01 sec.
Before Vestibular Stimulation					
CC	Mild Spasticity	28.0 Nt. 0.05 sec.	2.04 Nt. 0.05 sec.	-4.0 Nt. 0.13 sec..	1.80 Nt. 0.04 sec.
MC	Mild Spasticity	8.80 Nt. 0.18 sec.	2.36 Nt. 0.03 sec.	-6.40 Nt 0.09 sec.	3.30 Nt. 0.02 sec.
After Vestibular Stimulation					
CC	Mild Spasticity	7.15 Nt 0.18 sec	0.98 Nt 0.11 sec.	-2.02 Nt 0.07 sec	-0.83 Nt 0.008
MC	Mild Spasticity	9.45 Nt 0.10 sec	2.00 Nt .07 sec	2.00 Nt 0.04 sec	2.00 Nt .01 sec.

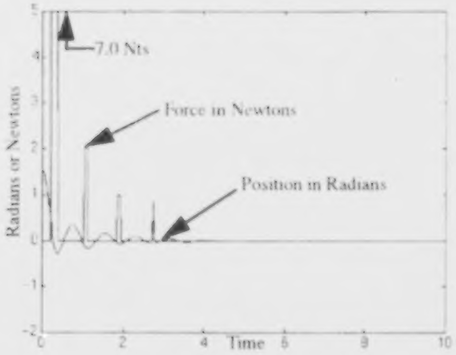

Figure 4
Timing and Amplitude of Active Forces
Spastic Model--After Stimulation

DISCUSSION

Table 1 above presents a summary of all the forces needed to optimize each of the five modeled subjects and conditions. Trends seen in the data suggest that muscle reactions to the Leg Drop Pendulum Test may be more normalized after vertical whole body oscillations. On a more fundamental level the values illustrate what can be learned from some simple modeling techniques. These numbers are clearly consistent with clinical observation and in fact reinforce known physiological phenomenon.

The changes in forces illustrated in these models are interesting, yet the author believes they beg a more fundamental question, what are their nature and form what mechanisms do they arise? Further modeling of the system will shed light on these questions as well. Replacing the square wave input forces with a good model of the muscle spindle should allow insight into the role these signals play in generating spasticity in the muscles of those with cerebral palsy.

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A QUANTITATIVE HEAD POSITION MEASUREMENT TECHNIQUE FOR THE EVALUATION OF TORTICOLLIS

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ABSTRACT

Torticollis is a condition in which involuntary muscle action causes the head to rotate into an abnormal position. No quantitative system exists which can measure head position in order to evaluate techniques used to treat this problem. Using an electromagnetic tracking device, a measurement system and activity protocol were developed to obtain objective data. Examples of the results of the measurements and the improvement with Botulinum injections will be presented.

BACKGROUND

Spasmodic torticollis is a condition in which the neck muscles involuntarily rotate and/or tilt the head into an abnormal right or left position. Bizarre head movements that occur in some patients tend to increase with certain activities or emotional conditions. Torticollis may interfere with work and activities of daily living. It also frequently results in pain. In most cases the cause is unknown, but it is thought to be associated with problems in the brain stem.

In order to keep their head in a neutral position, patients frequently use what are referred to as "tricks". These typically involve sensory stimulation, such as lightly touching the face.

Torticollis is treated with oral medications, injections of Botulinum toxin in the involved neck muscles, which results in muscle weakness, surgery, and by using various therapies, such as biofeedback, and electrical stimulation. The effectiveness of the various procedures has been difficult to determine because no good objective method exists to evaluate head position.

METHODS

A Torticollis Evaluation System (TES) was developed which records the position of the head using the Polhemus 3Space Isotrak 3-dimensional tracking system to provide continuous positional data. As part of the TES system, a protocol was developed to evaluate head position during four dynamic activities as well as measuring active range of neck motion in lateral tilt, flexion/extension and rotation.

The Isotrak device is based on electromagnetic techniques that are capable of continuously measuring angular position with an error of less than 1 degree. A small reference transmitter (3.5 x 3.5 x 6 cm) is mounted on either the back below the neck or on the anterior thorax. A small sensor (1.5 x 2.5 x 2.5 cm) is mounted on the head using an adjustable plastic band. The Isotrak system measures the distance and angular position between the source and receiver at a continuous rate of 10 samples/s. In this study of torticollis only the angular data of yaw, pitch and roll was used.

The testing protocol has two phases: Phase I measures the active range of neck motion as the patient moves his/her head through three cycles in each of the three planes of motion; lateral tilt, flexion/extension, and rotation. The system measures not only the primary angles, (angular change in the directed plane of motion) but the secondary angles (angular change in the two other planes where motion should not occur). For example, if the patient is doing flexion/extension, movements in rotation or lateral tilt would be considered secondary angular movements.

Phase II involves measuring head position during four dynamic activities: 1. sitting at rest for one minute without trying to control the head position starting from the best neutral position using "tricks", 2. sitting for two minutes attempting to hold the head in neutral, 3. walking in place for 30 s and 4. watching a video for 5 minutes.

RESULTS

Figure 1 shows an example of the range of motion results before and 4 weeks after Botulinum toxin injection. The labels above each group of curves indicates the desired plane of motion. Figure 2 shows an example of changes in average lateral tilt position during activities in Phase II following Botulinum injections. Also shown are the limits of the active range of neck motion.

Quantitative Head Position

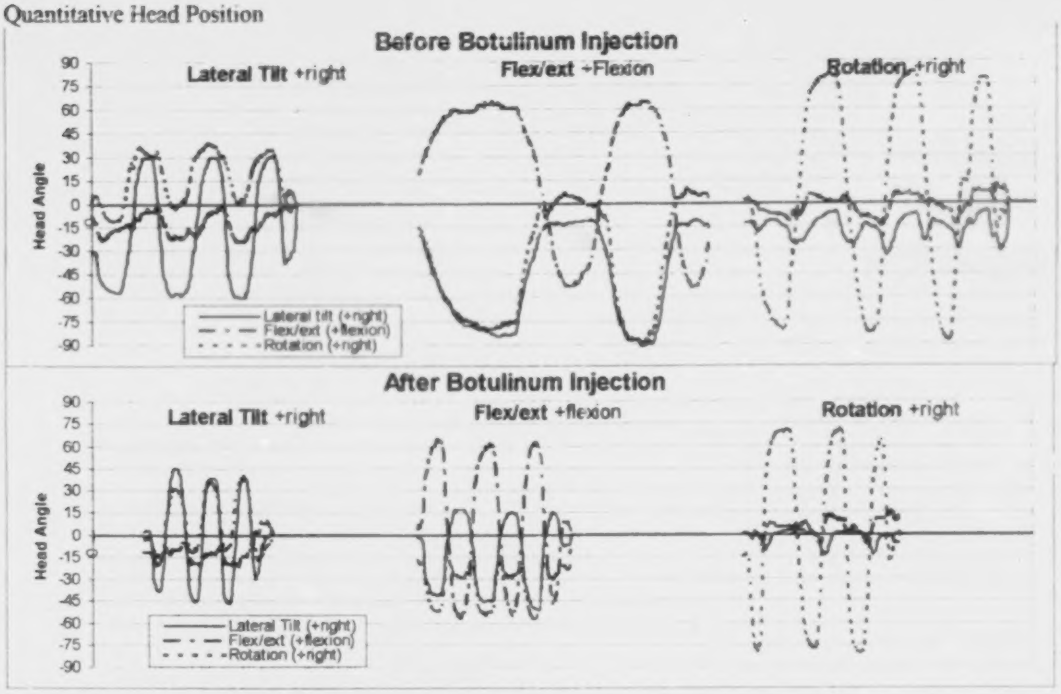

Figure 1 Range of Motion Measurement - Phase I

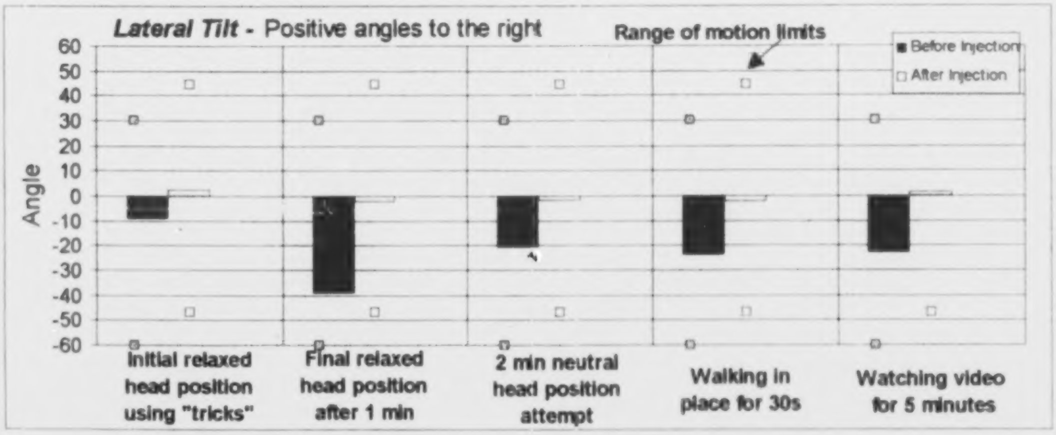

Figure 2 Phase II activity measurements

DISCUSSION

In the example, the range of motion results show that the change in secondary angles is significantly reduced and that for lateral tilt, the active range of motion is more symmetrical. The Phase II activity measures indicate the head position for these activities is on average in the neutral position. Five patients have been studied to date. Each patient has unique characteristics in their head position with variable results to Botulinum injections.

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A LOW COST GONIOMETER FOR CLINICAL GAIT ASSESSMENT IN REHABILITATION

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ABSTRACT

The movement of a joint during walking is of particular importance in clinical gait assessment. In most clinical settings, pathological conditions were usually described in a non-quantitative and subjective manner. Modern instrumentation, especially electrogoniometer, has provide clinicians with a portable device for objective measurement in joint motion. However, such device is still relatively expensive and clinicians who are busy with their routine assessments and treatments cannot afford extra time to download any collected data onto the computer. In view of that, this project aims to develop a low cost and simple mechanical device which can allow direct read out of the measured joint range during daily activities.

BACKGROUND

The study of human locomotion has been performed by many researchers over the past decades. Modern instrumentation, such as computerized motion analysis system, force platform and pedobarography, allows the capture of both kinetic and kinematic information during gait. These types of instrumentation are usually complex and expensive, and frequently require highly trained operators to devote relatively long time for data processing even though this process can be done by commercially available computer software. In fact, the most difficult part of a complete "instrumented" gait analysis is in the interpretation of the physiological meanings of the gait parameters. As most of the clinicians were not trained in their basic training to use such sophisticated and expensive instrument, application of instrumented gait analysis in conventional clinical settings is still not common. It is thought that a low cost and simple gait analysis device will be of utmost importance for instrumented gait analysis to become part of the routine clinical gait assessment procedures.

RATIONALE OF THE STUDY

During the clinical assessment procedures, observational gait analysis is frequently used in knowing the movement pattern of the body segments during walking. This technique is subjective and cannot easily be used to document pathological changes especially when the changes are subtle. Early recognition of gait deviations and continuous monitoring of changes in gait patterns are essential for rehabilitation specialists to select and implement an appropriate rehabilitation protocol.

Among various gait parameters, ranges of motion of various joints of the lower limbs are likely to be the most commonly used parameters for clinicians to document the functions of the joints. In clinical practice, the ranges of motion of a joint can be measured in terms of the differences between either physiological limits or functional limits. For the physiological range of motion measure, it refers to the maximum range of motion that a joint can reach either by passive or active action. For the functional range of motion measure, it refers to the "useful" arc, within the physiological range of motion, that a joint moves during walking activities. Moreover, different functional measures can be obtained when the subject is walking on a level surface or a non-leveling walking condition such as stair climbing, or up and down a slope. In principle, the physiological range of motion can be measured with a higher accuracy than the functional range of motion, as the former range is measured with the limb segments in static postures while the latter one has to be measured when the limbs are in dynamic motion. Additionally, from the clinical view point, the functional range of motion is of higher clinical significance than the physiological range of motion as it describes the actual performance of a joint. Although there is now commercially available electronic device such as electrogoniometer, which can provide a fairly accurate measure of the functional range of motion, its application in clinical assessment is still not popular in most clinical settings in Hong Kong. Besides the fact that such device is relatively expensive, most clinical settings in Hong Kong are very busy in their daily duties. Clinicians really need a device which is even more simple to apply and will not take them much time to learn. This is the primary motive of this project to develop a low cost and simple mechanical measuring device which can serve this particular function.

DESIGN CONSIDERATIONS

The objective of this project is to develop a low cost and simple mechanical goniometer which could be used to measure quantitatively the functional ranges of motion of various joints of the lower limbs. Instead of recording continuous changes in the joint angle during a gait cycle, we focused on 3 essential parameters which were believed to be able to represent and differentiate the gait deviations of a subject from normal. These parameters included the maximum flexion and extension of the joint during walking activities and the neutral position of the joint in relaxed standing posture. In addition, if this new goniometer should gain acceptance in clinical practice, the following criteria need to be incorporated:

1. low cost;
2. easy to use;
   - no particular training is required
   - no calibration is required
3. able to provide a direct read out of the measurements;
4. measurements need to be accurate, repeatable and easy to access/record; and
5. maintenance free.

EVALUATION

To validate the performance of the new mechanical goniometer, the accuracy of the device was evaluated under different alignment situations. Moreover, the functional ranges of motion of hips, knees and ankles of 10 normal volunteers (age ranged from 22 to 52 years old) were measured during level walking, and climbing up and down a stair. The results were with those obtained by commercially available electrogoniometer (Penny & Giles, U.K.). The accuracy of the new device for measuring functional range of motion was found to be within ± 1°.

CLINICAL APPLICATIONS

The evaluation of treatment efficacy is a common goal of gait assessment conducted in clinical situation. Usually, normal data are required as references for outcome measures in gait evaluation for patients where both legs are affected. This would involve a lot of work and time to establish a "normal" database which can represent our daily activities. The newly developed mechanical goniometer can be used to document the functional ranges of motion of various joints of the lower limbs for different age groups and sex. The measurement can be conducted in any clinical settings and even in outdoor environment.

In most clinical situations encountered with patients suffered from neurological disorders, such as stroke and tumor, or other sports or orthopaedic injuries, such as fracture, joint replacement and ACL injuries, etc., it is often to have only one side of the lower limbs affected. As information regarding pre-injury is rarely available, the unaffected limb is frequently used as the reference or control for documenting the progression of the gait improvement during the rehabilitation period. The assessment of symmetry of the movement is also commonly used in the evaluation of hemiplegic gait pattern. As this new mechanical goniometer can easily be used bilaterally to document the symmetry of the gait of a subject, the progress during rehabilitation, as part of the outcome measures, will be very useful for investigating the effectiveness of various types of treatment prescribed. Further experimental studies have also been initiated to validate the reliability of the device in clinical application.

The new device has also been applied by clinicians during prosthetic socket alignment process. In conventional clinical practice, the ranges of motion of the joints of an amputee are "observed" by the prosthetist for adjusting the prosthesis alignment. However, the time required for establishing a proper alignment would highly depend on the skill and experience of the clinician in correlating the observed joint angles with the necessary adjustments that are required. This new goniometer has been used to assist the prosthetist in extracting joint angles information in a quantitative manner, which can be documented with the necessary adjustment procedures. The result gathered would be valuable for enhancing the techniques in achieving an optimum prosthesis alignment in meeting various demand encountered during daily activities.

DISCUSSION

It should be noted that this new mechanical goniometer is designed to measure the functional range of motion of a joint. However, the user should take note of the joint angle at its initial (neutral) posture. If the joint is in hyperextension

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initially, there could exist chances that the functional range of motion of the joint during walking may not reach the initial limit. In this case, the corresponding functional range of motion obtained should be considered carefully.

CONCLUSION

A new simple mechanical goniometer has been designed and developed to allow clinicians to perform quantitative clinical gait analysis at an affordable cost. The measurement of the functional range of motion of joint angles provides an objective way to document normal and pathological gait patterns and can be used as references for outcome measures after clinical treatment. In addition, this simple device also allow clinicians to collect essential information of joint movement due to different function deficiency resulting from injuries or diseases. This also helps to establish a reference database for joint range of motion in different conditions of normal gait, including level walking, stair climbing and slope walking.

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INDIVIDUALIZED VIDEO-BASED STROKE REHABILITATION HOME PROGRAM

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Abstract

We have shown that evidence of stroke-related dysfunction can be elicited and examined through video observations of subject performance of specific transfer tasks. Based on this prior research, we hypothesize that such patient-specific video footage can be used to create a take-home educational videotape documenting correct vs. incorrect transfer performance and patient-specific therapist recommendations. A home program incorporating a customizable multimedia transfer training format is hypothesized to increase the effectiveness of subjects' home transfer performance, increase educational carryover from the clinic to the home, and decrease caregiver injuries resulting from improper transfer techniques. The Videotape for improved Rehabilitation Activity Performance (V-RAP), being developed at the Veterans Affairs Palo Alto Health Care System Rehabilitation Research and Development Center (VAPAHCS RRDC), is the instrument which we will use to test this hypothesis.

Background

Demographic Factors of Stroke

There are currently 1.5 million stroke survivors in the United States. More than half of these individuals have significant residual physical disability and functional impairment. Survivors of stroke constitute the largest group of patients receiving rehabilitation services in this country (1).

Family members of stroke victims also have their lives changed. Virtually all stroke survivors (97%) are able to continue living in the community with the assistance of a primary caregiver (2). Accordingly, efforts should be made to target family members and to potentiate their effectiveness as support providers through education and specialized training and assistance.

Work Accomplished

A prototype, termed the Functional Performance Assessment Tool (F-PAT), was designed to conduct functional outcome efficacy studies of treatment interventions using a multimedia approach (3). In collaboration with the VAPAHCS Upper Extremity Clinic, a set of twelve functional tasks was derived to demonstrate the effects of repetitive strain injury (RSI) of persons with paraplegia who use manual wheelchairs. It was felt that the performance of these activities by patients with RSI, acting as study participants, would elicit visual evidence of dysfunction related to the subjects' RSI conditions. Analysis of video segments of these tasks effectively assisted a clinician in preparing a treatment plan for the patient, sharing patient information with members of the multidisciplinary team, and creating and implementing a patient-specific home program. The effectiveness of video analysis in rehabilitation as discussed here provided the basis for the development of the home rehabilitation program videotape. Furthermore, standardized task selection criteria and evaluation materials created for F-PAT were transferred to the development of V-RAP.

Statement of the Problem

Training in the performance of transfers, an integral aspect of a CVA education program, represents one of the most important issues in home carryover from the hospital setting. Wheelchair transfer skills are among the most important skills that must be mastered by persons with CVA (4).

The need for carryover in transfer safety techniques to the patient's home environment is validated by the incidence of faulty transfer procedures. Of all the wheelchair accident locations in a recent study, over half occurred in the wheelchair user's home. Furthermore, transfer-related injuries to caregivers and family members accounted for approximately 14.1% of all wheelchair-related non-user injuries between 1986 and 1990, or about 1,600 reported injuries (5). When the injury affected a caregiver, lack of proper education was frequently implicated. Several recent studies, including a wheelchair-related fatal accident study, found that the skill level of attendants was an important consideration in wheelchair-related accidents (6).

Approach

Overview of study

Research staff from the RRDC are collaborating with therapy personnel from the Comprehensive Rehabilitation Center (CRC), where 15 subjects will be recruited. Subject selection criteria are the following: subjects must be hospitalized for having sustained a CVA, be in the age range 35-65, and exhibit no cognitive or psychological impairments severe enough to interfere with activity performance or ability to learn new information. The subjects will be randomly divided into three groups of five subjects each. The first group will serve as the control group for the hypothesis, and will leave the hospital with traditional home program materials (no videotape). The second group will leave the hospital with a premade educational videotape consisting of a therapist performing the closed set of V-RAP activities properly; footage of these subjects performing the task set will not be included on their videotape. The third group will be videotaped performing the transfer tasks, and a videotape containing subject-specific video footage will be compiled and sent home with the subject in addition to the premade tape of the therapist performing the activities.

The study has been designed to consist of three phases. In Phase I, the RRDC V-RAP staff and the CRC therapy staff will collaborate to break down each predetermined transfer into its specific performance components. For example, components of a wheelchair to bed transfer would include, but not be limited to, the following:

- Scoot forward to edge of w/c
- Lock brakes
- Lean trunk forward
- Proper placement of feet and hands

For each component, standardized videotaping and evaluation criteria and specific hazard areas will be identified during this phase. These areas will be given special attention by the therapist when performing the transfers on videotape.

In Phase II, the CRC therapist will videotape subjects performing a closed, predefined set of transfers according to the specified standardized criteria. In the proposed work, the specified videotaping criteria will be augmented by video templates and examples that will aid the therapist in recording the subjects performing the specific activities. These templates and examples will be presented visually, using graphics, storyboards, and video segments. These will help the therapist, who may have no training in video composition, to produce a consistent video record suitable for use as a basis for training and evaluation.

Phase III will be implemented upon completion of videotaping. At this time, the therapist will collaborate with V-RAP research staff in identifying video clips most suitable for inclusion in a home program videotape. The VIRAP staff will create the videotapes, composed of correct and incorrect task set performance for subject identification and comparison purposes, using the VideoDirector™ software program (7). VideoDirector has been tested and shown to be capable of sequencing predetermined video clips onto a videotape in accordance with the needs of V-RAP educational videotape production. The sequencing and compilation of video clips to produce a finished home program videotape using VideoDirector will be done outside the clinic by the V-RAP research staff. Further studies may indicate the need and include recommendations for the therapist to become more active in the video clip compilation process.

V-RAP research staff will also videotape therapist performance of all transfers for inclusion in patient educational videotapes. Subjects in Group 2 will receive only this footage on their home program videotapes. Subjects in Group 3 will receive this footage alongside footage of their own performance of the identical transfers for analysis, comparison, and potential activity performance modification. Subjects will be given specific directions as to when and with whom to view the tape, what to look for, and how to view it most effectively.

Implications

Significance of this research

Functional assessment information obtained through observation of activity performance can provide numerous areas of focus for rehabilitation. For example, proper activity performance can be compared with dysfunctional performance of the same activities. A patient's videotaped activity performance can also be analyzed over time to establish specific progress made toward functional goals, thus promoting the facile establishment of new, farther-reaching goals based on specific functional improvements, not on chronological expectation timelines.

Analysis of video footage for educational purposes can be beneficial to caregivers as well as patients. Utilizing video, caregivers are given the ability to view their own deficit areas and obtain specific instructions from a therapist regarding home treatment program performance. This integration of therapist feedback into a patient's self-monitored home therapy program is seen as the first step toward interactive therapist-patient and therapist-caregiver relationships extended outside the acute setting. The future development of real-time video links connecting therapists, patients, and caregivers would eliminate the need for transportation to clinics while allowing high-quality interactive treatment and home program review and modification from a distance.

Discussion

The assessment of study effectiveness will be based on each subject's one-month follow-up visit with a physiatrist and physical therapist, and will be assessed in two ways:

> (1) The physical therapist will review the subjects' home program with them and monitor subject performance of standard transfer tasks as performed in the home program.
>
> (2) The physiatrist will record subject answers to routine questions. These answers will be utilized to evaluate effectiveness of V-RAP materials and will be compared across subject groups. Answers will be recorded for questions pertaining to subject satisfaction and motivation, subject ratings of transfer performance improvement, and incidence of subject or caregiver injury sustained from faulty transfer performance.

Our hypothesis will be proven if the data analysis can demonstrate the following:

- Subject satisfaction ranking of the V-RAP home program will be at least as high as that of the conventional home program;
- Subjects using V-RAP will improve in transfer performance and feel comfortable performing transfers more quickly than subjects using traditional home program materials;
- Subjects using V-RAP will report fewer transfer-related accidents or injuries than subjects using traditional home program materials.

Future plans include the complete incorporation of V-RAP into a rehabilitation clinic and the use of V-RAP by all therapists in that setting for the creation of home treatment program videotapes. Additionally, therapist criteria regarding transfer safety and training techniques will be recorded to form the basis for the future design of a transfer training expert system.

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DESIGN OF A HAND EXTENSION EXERCISER

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ABSTRACT

An increase in awareness of cumulative traumatic disorders (CTDs) of the hand, like carpal tunnel syndrome, has sparked the development of preventative devices. One method of preventing the occurrence of CTDs is to increase the functional capacity of the hand. This can be done through strengthening and conditioning. There are many devices available which can work the hand in flexion, while the availability of hand exercisers for extension are limited and are narrow in their functional capabilities. An ideal hand extension exerciser allows for independent exercise for each of the joints, throughout their entire range of motion. Inherent in the ideal exercise motion is the design obstacle of having minimal space available to design within. When the hand is clenched, the palm is almost void of any space. The design solution to these limitations is a mechanism which is mounted to the top surface of the hand. The mechanism resists angular motion of the joints by means of coil springs. Early prototypes have shown the designs effectiveness. Future work involves refining the design based on evaluations.

BACKGROUND

Cumulative traumatic disorders (CTDs) are neural, vascular or musculoskelatal abnormalities resulting from an overuse of the body. By definition, CTDs occur when the forces acting on the body repeatedly exceed its functional capacity [2]. The prevention of CTDs requires that limb use not exceed its functional capacity. Therefore, there are two ways to approach prevention of CTDs. The first is to limit the function or the use of the limb, such that it does not exceed its capabilities. The second, and most empowering approach is to increase the functional capacity of the limb. This is commonly done through strengthening and conditioning. Strengthening and conditioning allows the limb to function safely within its daily activities and still prevents the occurrence of CTDs.

Function of the hand during every day activities is primarily in flexion. We use the palmer surface of the our hands to grip objects more commonly than we use the dorsal surface to push them away. This pattern of use lends itself to a muscular imbalance about the joints of the hand. Finger flexors are commonly twice as strong as their corresponding extensors [1]. Research on the lower extremity has shown that an abnormal balance of agonist: antagonistic muscle strength is associated with both acute injuries and CTDs [2,3]. Research at Beneficial Designs, Inc. has been proposed to determine whether a similar imbalance is associated with the hand and wrist injuries experienced by wheelchair users. In anticipation that there is a correlation between muscle imbalances and CTDs, Beneficial Designs, Inc has proposed the development of a device which strengthens the extensor muscles of the hand.

STATEMENT OF THE PROBLEM

The purpose of this project is to design and develop a hand extension exerciser. The key criteria of the design is to achieve a full range of motion as well as have independent, adjustable resistance to each of the finger and thumb joints. The device will force flexion and resist extension, be simple to use, and have a non-medical appearance.

RATIONALE

There are many commercial products on the market which exercise the hand in flexion (usually classified as tension relievers). Available hand extension exercise products satisfy only a limited number of the desired design criteria. The most common area in which the current products are deficient is in their capability to exercise the full range of motion for each joint. Generally, these products do an excellent job in exercising one or two of the major joint classifications but ignore the third. Additionally, when two of the joint classifications could be exercised, they would need to be exercised separately, rather than in one simple and complete motion. Another setback to some of the designs was the inappropriate distribution of resistance to the various joints. The functional capabilities of the MCP (metacarpophalangeal) joints greatly exceeds that of the DIP (distal interphalangeal) joints. Therefore, the resistance should be applied to the joints in a similar manner, rather than equally or, in the worst case, opposing this order.

After conducting a thorough investigation into the state of the art, as well as having done a patent search for any ideas that had not yet reached the market, it was concluded that a completely new and innovative design was justified and required.

DESIGN AND DEVELOPMENT

The first stage of the design was to decide upon a motion which would achieve the desired results. The approach to deciding on a particular motion was to first examine what appeared to be the most natural solution and then to have that motion critiqued and modified by both an exercise physiologist and then by a physical therapist, specializing in the hand [4]. The result of this approach defined a motion which maximized the design parameters of being simple, natural, and effective. The motion begins with the hand as a clenched fist (the thumb pressing against the middle phalanx of the index and middle fingers), and ends with the hand completely extended, to a comfortable degree. Inherent in this motion is the premise that exercising isotonically is preferable to isometrically. Isometric exercise results in no motion at all. To address this uncertainty, the design criteria was modified to include an ability to lock the motion at any particular joint, allowing both isometric and isotonic exercise.

Once a motion had been decided upon, the actual design of the device began. Many obstacles arose during the conceptual design phase which were responsible for the discarding of several promising preliminary design concepts. Of the obstacles, the most overwhelming has been the fact that, if the hand is closed into a complete fist, there are many locations on the hand which become completely void of space onto which any device could be attached. On the palm side, the fingers, as well as the space between the fingers becomes completely sealed. On the dorsal side of the hand, the resting place of the thumb obstructs access to the middle phalanxes on the index and middle fingers. Because the phalanxes are short, the angular motion at the joints translate into minimal linear displacements between the middles of the phalanxes as the hand flexes and extends. This minimal displacement rules out the use of many linear resistance devices. When designing angular resistance devices to exercise the hand it is critical to design the device so that its hinges are located at the same location as the hands joints, or to design the device such that it does not inhibit the natural motion of the hand; this will ensure that the exercise does not cause discomfort or injury during use.

Due to the limited space available for a device to be incorporated onto the hand, developing a method to apply angular resistance to the hand's extension became the primary focus of the design. As shown in Figure 1, the resistance system developed is attached to the dorsal surface of the hand. It occupies minimal distance from the surface while the hand is clenched, and is allowed to extend from the surface as the hand is extended. The device depends upon the hand for pivot points, and therefore is not uncomfortable to operate.

The base plate in Figure 2 is attached to the finger between the joints. The attachment of the base plate to the fingers is presently accomplished using a glove. The base plate is sewn onto the dorsal side of the glove at locations correlating to the midpoints of each phalanx. A specific glove has been chosen to minimize hindrance of the hands motion, while maximizing rigidity around the hand.

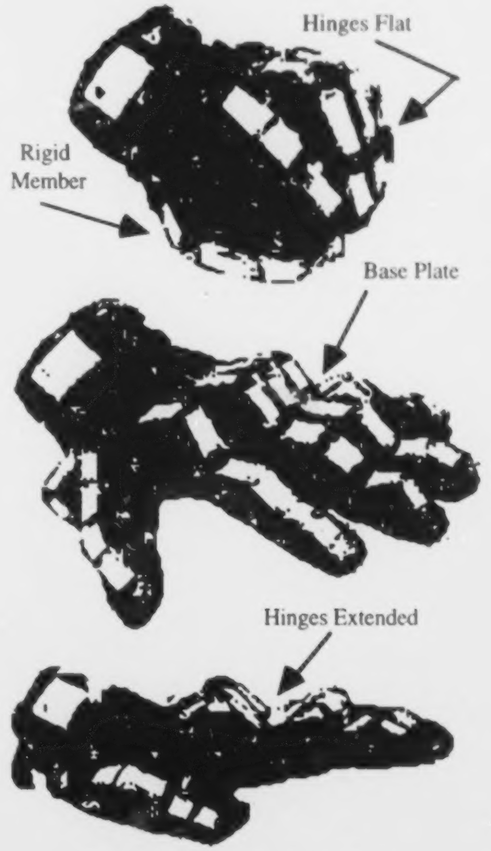

Figure 1: Motion Analysis Glove

This type of motion is achieved by placing rigid members between hinges, located at each joint of the hand, as well as between each of the joints. A coil spring between each of the hand's joints forces the adjoining rigid members to remain flat. Figure 2 is a layout drawing of a single resistance mechanism. This orientation of the rigid members occurs when the hand is fully extended. The displacement of the coil spring during exercise is approximately 90 degrees. The coil spring is preloaded when the two adjoining members are flat, in order to ensure resistance to extension throughout the entire motion.

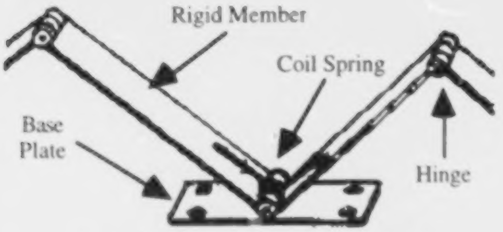

Figure 2: Angular resistance mechanism
(Base Plate fixes to phalanx)

The resistance's are adjustable by the changing the coil springs. The stiffness of any particular spring will proportionally effect the difficulty by which the hand can be extended. The size of the device follows the standard fitting guidelines for gloves, where small, medium, and large are the described fits.

EVALUATION

Thus far, the prototypes are performing as had predicted. Mounting the base plates tightly to the finger has been a critical issue in ensuring that the resistance device is effective throughout the range of motion. The present prototype appears to be useful on various size hands, reducing the number of required sizes for multiple users. The hinged resistance mechanism is a significant design innovation which will lead our future design efforts.

DISCUSSION

Future Work

The early prototypes of the design have shown their potential for success. Future efforts will be focused on refining the resistance mechanism and improving the interface between the resistance mechanism and the hand. Additionally, the devices performance will be assessed by both the staff at Beneficial Designs, Inc. and by a mechanical engineering advisor at Santa Clara University.

The resistance mechanism will be refined by careful selection of coil springs and member lengths. Coil springs must be linear within a small range of motion (90 degrees or less). Also, the coil springs must be either adjustable in stiffness or be available in many slightly varying stiffness, in order to allow for gradual strength development and thus reduce the chance of injury, due to over exertion.

The use of a glove as the device / hand interface may not prove to be a necessary structural element. In the event that the resistance hinges and hand joints create a sufficiently stable structure, the glove may be replaced with a series of fingerloops and a larger piece which fits over the back of the hand. The advantage of eliminating the glove is an increase in ventilation to the hand. These interface components are rigid thermoplastics, which have been molded into the shape of the hand. The inside of the interface is a soft spongy material (i.e.. neoprene). A strap will wrap around the palm, securing the device to the hand

Significance

The hand extension exerciser holds promise in the prevention of CTDs. The relatively high rate of CTDs occurring in the last decade shows us that there is a need for such a device. The approach to preventing CTDs using the hand extension exerciser is to increase the functional capacity of the hand to a level beyond its daily demands. The device is designed to be versatile, aesthetically pleasing, and easy to use. Such characteristics will make it a desirable product to a wide variety of consumers and its versatility will allow it to be used in physical therapy clinics, while traveling, in exercise gyms, and at home.

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FUNCTIONAL IMPACT OF ASSISTIVE TECHNOLOGY ON PEOPLE WITH HEMIPLEGIA FROM STROKE

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Abstract

The use of assistive technology is a traditional treatment approach of occupational therapists working with patients in rehabilitation. The range of assistive technology used in rehabilitation is vast, from "low tech" long handled sponges to "high tech" wheelchairs and communication devices.

While the use of assistive technology with patients with stroke is widely accepted, it has not been substantiated by research in functional outcomes.

The OT FACT computerized documentation program was used to collect data on individuals with stroke on an inpatient rehabilitation units. Data were collected for each patient unit at admission, at discharge and at a two to three month follow-up call. Independent variables included demographics, Functional Independence Measure (FIM) and the use of assistive technology devices. Results of the study demonstrate the effectiveness of OT FACT in data collection and demonstrate the change in functional outcomes of patients with stroke using assistive technology.

Background

The use of assistive technology for people with disabilities has become a powerful medium for facilitating independence and personal productivity. The assistive technology field has always relied on the good intentions of funding agencies (such as medical assistance and medical insurance companies) to pay for devices for the people who will benefit from assistive technologies. While the lack of data and scientific evidence to support the use of assistive technology has always been a problem, the common sense approach has usually been adequate. Recently however, public funding systems have been instituting more fiscal restraint. Consequently, more empirical data are necessary to justify the expenditures of assistive technology devices and services which can range from a few dollars to many tens of thousands of dollars.

Superficially, documenting the usefulness of assistive technology seems to be as simple as recording how well it works. Assistive technology suppliers and service providers have not found this to be so easy. The reason for the difficulty is two-fold. First, virtually no instruments have been created to measure the impact of assistive technology. Second, it is not even certain what constructs best measure the effectiveness of assistive technology. An instrument designed to truly measure assistive technology as defined in federal law (widely) must be extremely flexible and encompassing. Data collection instruments have traditionally been much more specific. OT FACT

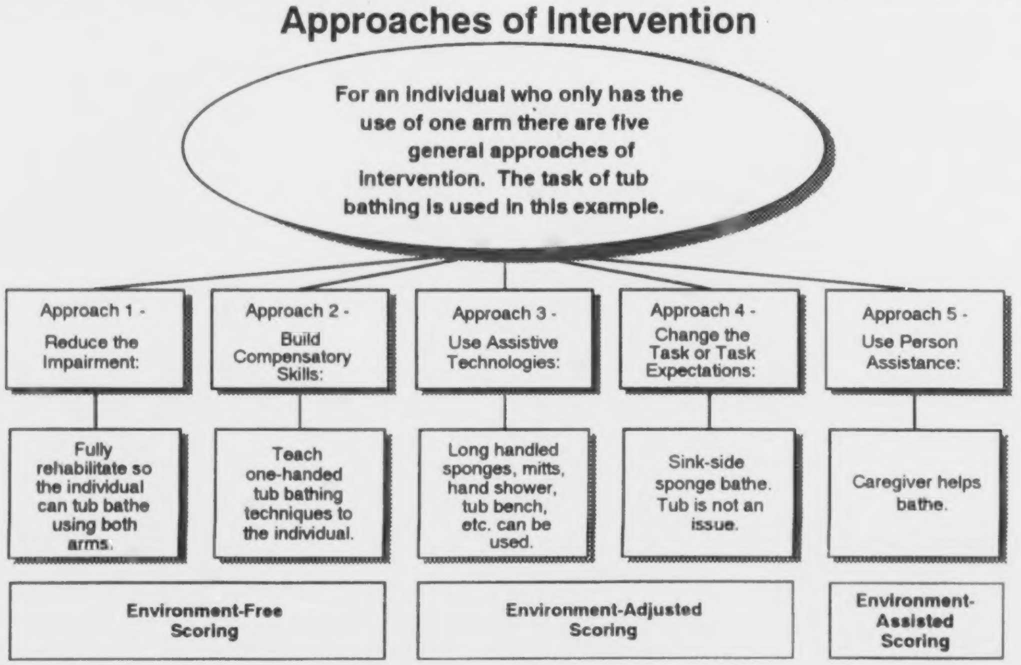
Approaches of Intervention
For an individual who only has the use of one arm there are five general approaches of intervention. The task of tub bathing is used in this example.
Approach 1 - Reduce the Impairment:
Approach 2 - Build Compensatory Skills:
Approach 3 - Use Assistive Technologies:
Approach 4 - Change the Task or Task Expectations:
Approach 5 - Use Person Assistance:
Fully rehabilitate so the individual can tub bathe using both arms.
Teach one-handed tub bathing techniques to the individual.
Long handled sponges, mitts, hand shower, tub bench, etc. can be used.
Sink-side sponge bathe. Tub is not an issue.
Caregiver helps bathe.
Environment-Free Scoring
Environment-Adjusted Scoring
Environment-Assisted Scoring

Figure One: Approaches of Intervention

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(Smith, 1992), available from the American Occupational Therapy Association is a computerized, comprehensive, functional assessment that is being tested here as an outcome measurement tool.

The national Center for Health Statistics cites that over 34 million civilian non-institutionalized Americans are limited in their activity due to long-term disability. An additional 2 million are residing in long-term care facilitates. A large percentage of these individuals use assistive technology devices. Studies have found that some populations of disability use an average of more that six devices. As health care dollars become more rationed, decisions will increasingly be made between allocating dollars for therapy and rehabilitation of people with disabilities or for compensatory interventions such as the use of assistive technologies. Figure 1 shows common approaches used in rehabilitation of which assistive technology is shown as a key area of practice.

Research Question

Does assistive technology intervention as provided by occupational therapy practitioners improve the functional outcome of individuals with stroke?

Methods

The study is structured as a simple repeated measures multi-variate design. The independent variable includes a number of demographic variables, Functional Independence Measure (FIM) and the use of assistive technology devices.

Assistive technologies were listed from the Abledata catagories (DOS Abledata, 1992). Please refer to figure two for examples from the assistive technology list. Five in-patient unit field sites are involved. Dependent variables are observed at three points in time: admission to the rehabilitation unit, at discharge from the unit and at a two to three month follow-up. Dependent variable data are all collected with an intra-class correlational analysis for the reliability assessment.

The OT FACT documentation software used for data collection. OT FACT elicits the subjective judgements of raters and qualifies the judgements through a branching questioning structure called Trichotomous Tailored Sub-Branching Scoring.

This study collected the Environment Free data (performance across functional areas without assistive technology) and Environment assisted data (with technology). The use of double scoring procedures at discharge allows for teasing out the use of assistive technologies. The therapists/data collectors also collect the independent variable data.

Food Preparation
Non-skid containers
Adapted cutting board
Pan holder
Communication Devices
Magnifyer
Book holder
Built-up writing tools

Figure Two: Assistive Technology examples

Results

Preliminary data demonstrates the significance of using assistive technology in the outcomes of patients with stroke. A case example, "GS", a 66 year old male who suffered a left cerebral vascular accident, had 17% improvement in his OT FACT score in Activities of Performance: personal care activities. (See figure three.) His intrinsic improvement in rehabilitation was 57%, adding the use of assistive technologies, and his improvement increased to 70% Figure four shows the changes in the activities of daily living levels, comparing initial assessment scores with discharge "environment free" and discharge "environment adjusted" scores. The data collected on assistive technologies used by "GS" included: tub bench, grab bars, suction toothbrush, velcro, one-handed insulin draw, easy open bottles, and small based quad cane. Data collection continues at the five research sites.

Discussion

The preliminary data indicate that the use of assistive technologies does appear to make a difference in the functional outcomes of patients with stroke. The technologies that are most used by stroke patients appear to be the "low tech" items such as grab bars, adapted toothbrushes and canes. This study is a follw-up to Smith's (1993) *Assessing the impact of assistive technology using OT FACT version 2.0.* As predicted, OT FACT demonstrates success in its usefulness as an outcomes measurement tool for a stroke population. Current interests in measurement includes frequency measures and qualitity of life indices, including self-satisfaction issues. OT FACT has the flexibility in its design to measure self-satisfaction, to allow for cooperative patient-therapist goal setting and to tailor the outcome indicator specific to the population.

	Discharge		Discharge		Difference	
	.Fre		.Adj			
	Score	%	Score	%	Score	%
I. Role Integration	32	0%	32	0%	0	0%
II. Activities of Performance	172	20%	206	7%	34	17%
III. Integrated Skills of Performance	56	7%	56	7%	0	0%
IV. Components of Performance	50	14%	50	14%	0	0%
V. Environment	24	0%	24	0%	0	0%

Figure Three: General Levels

	Initial		Discharge		Discharge	
	.Fre		.Fre		.Adj	
	Score	%	Score	%	Score	%
II. Activities of Performance	49	77%	172	20%	206	7%
A. Personal Care Activities	47	72%	139	20%	173	3%
1. Cleanliness, Hygiene,	16	79%	68	15%	86	0%
2. Medical & Health Management	8	70%	18	31%	26	0%
3. Nutrition Activities	4	82%	16	28%	20	10%
a. Feeding/Eating	4	72%	12	15%	14	0%
b. Meal Prep & Clean up	0	100%	4	50%	6	25%
4. Sleep & Rest Activities	7	42%	12	0%	12	0%
5. Mobility Activities	4	75%	10	38%	14	13%
a. indoor	4	67%	8	34%	12	0%
b. outdoor/community(private)	0	100%	1	50%	1	50%
c. outdoor/community(public)	0	100%	1	50%	1	50%
6. Communication Activities	8	43%	13	8%	13	8%
a. speaking	1	50%	2	0%	2	0%
b. writing	0	100%	1	50%	1	50%
c. reading	1	50%	2	0%	2	50%
d. telephone	0	100%	2	0%	2	0%
e. sexual expression	6	0%	6	0%	6	0%
7. Assistive Device Repair	0	100%	2	0%	2	0%

Figure Four: Activities of Performance Levels

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TECHNIQUES FOR MEASURING LUMBAR CURVATURE AND LUMBAR SHAPE OF THE SPINE: A LITERATURE REVIEW

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ABSTRACT

The inward curvature of the lumbar spine is widely regarded as a natural and desirable physical adaptation for the standing posture. The consensus among researchers and clinicians is to maintain the curvature, or lordosis, as humans assume seated postures. Several techniques have been applied to measure lordosis that have yielded varying degrees of success. Radiographic methods and, to a lesser extent, segmental vertebral body tracking are the only methods identified as capable of precisely measuring intersegmental position. Alternatively, skin surface instrumentation techniques provide gross measures of spinal shape and are commonly applied clinically.

BACKGROUND

In recent decades there has been increased interest in lumbar lordosis measurement. The wide variety of historical measurement techniques may be classified as either clinical or laboratory-based approaches. Clinical methods are generally easier to administer and provide an adequate degree of precision for its intended application. The precise laboratory-based methods are characterized by increased costs due to highly specialized personnel and instrumentation. With few exceptions, both approaches are limited to the static measurement of a phenomena that is both time and posture dependant. Traditional measurement methods are marked by varying levels of reliability and the industry remains open to improved techniques of lordosis measurement.

Movement of the lumbar spine has been evaluated by researchers for over a hundred years. In 1836 Weber and Weber published an early paper that evaluated spinal mobility.[1] This work was followed by several studies through this century and the body of literature is now extensive, particularly as a result of research in recent decades. In recent years, instrumentation and data collection technologies have permitted extensive analysis of the lumbar spine shape.

RESEARCH QUESTION

Clinicians and researchers have long been interested in quantifying back shape and its changes. Can a practitioner be confident that the results of common measurement methods are accurate? The quantity of journal articles that have promulgated and evaluated several methods (e.g. flexible ruler, dual inclinometer, skin distraction) is extensive. Several authors have reported high correlation between methods thus suggesting valid results. However, a close review of the literature reveals inconsistencies in reported device performance over several studies.

RESULTS

Lumbar lordosis measurement methods measures a) spinal position b) spinal motion or c) spinal shape. Physical therapists might seek a device that measures the *position* of the lumbar spine in flexion and extension thus permitting range of motion evaluation throughout the rehabilitation process. Alternatively, industrial applications for seating designers or ergonomics researchers may be interested in characterizing the *movement* of the lumbar spine during a work session. Surface techniques are reasonably accurate in the measurement of the total lumbar motion.[2] However, there is poor correlation between intersegmental motion when measured radiographically and at the surface of the skin. Bryan[3] points out that a direct comparison between roentgenograph measurement methods and external lumbar lordosis measurement methods cannot be done since the basis of physical measure differs. Attempts to validate results in repeat studies have been unsuccessful.[3] There is no clear agreement of the validity and reproducibility of lordosis measurement methods.

DISCUSSION

Radiographic techniques have been applied to quantify lordosis and evaluate range of motion for years.[4,5,6,7,8] X-ray techniques are considered the most accurate clinical method of lordosis measurement since the measure is not effected by soft tissue variation across subjects. Biplanar radiography has been used to quantify motion in three axes[9,10] and can achieve highly precise measures of vertebral bodies in space.

Photographic evaluation of lumbar lordosis has been attempted in several studies.[11,12,13] The reliability of such techniques are dependant on the precise methodology and instrumentation applied. The inclinometer,[14,15,16] Dual inclinometer,[17,18,19] flexible ruler,[20,21,22] and skin distraction methods[23,24,25,26] are common clinical methods of quantifying lumbar lordosis.

Several goniometers,[27,28,29,30,31,32] and visual motion analysis systems,[33,34] have also been applied in research settings but are not routinely used clinically due to relative complexity and cost. Electro-goniometers have recently been applied to obtain time-dependant change in posture when measuring the postures associated with several tasks.[35,36,37,32,38] Spatial position sensors have been used to quantify relative position and movement in the spine and are regarded as highly accurate tools to characterize posture.[39,40,41]

Initial pilot studies from an Intervertebral Motion Device shows promise for future analysis but the process is currently limited to study trials.[42,43] Widespread clinical use is not likely due to its invasive nature and high cost to implement.

Considerable studies have been conducted to investigate and validate the wide variety of lumbar lordosis measurement tools. Several tools are perceived to have restrictions that limit their utility in clinical environments. Reliability, reproducibility, safety and cost are often cited as limitations to the existing measurement methods. According to Bryan, "...a nonroentgenographic method of measuring postural curves would be an excellent clinical and research tool if the method was inexpensive, expedient, reliable, and valid."[3] Despite the diverse noninvasive measurement techniques, the validity of several methods have recently been challenged by investigators. The industry appears ready for a new device/technique to overcome some of these issues.

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THE DEVELOPMENT OF AN EXTENDABLE BELOW-KNEE PEDIATRIC PROSTHESIS

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ABSTRACT

Pediatric prosthetic legs typically are scaled-down versions of prostheses that were initially designed for adults. Most prosthetic legs currently in use do not address the children's specific needs. As a child grows the entire leg needs to be replaced

An extendable patellar-tendon-bearing below-knee pediatric prosthesis has been designed, fabricated, and tested in comparison to an existing prosthesis. The pediatric prosthesis has extendable pylons, an energy storing foot, and a dynamic response ankle. This design will enable the child to wear the leg over an extended time reducing the replacement cost of new legs. The method of aligning the prosthesis for the patient allows both medio-lateral and anteriol-posterior slide. The prosthesis was designed with two goals in mind: the first was to allow the prosthesis to grow with the child; the second was to decrease the frequency of replacing the leg which in turn will reduce the replacement cost for each new prostheses.

Problem Statement

The National Center for Health Statistics (NCHS) conducted a study in 1992 to determine the number and types of disabled individuals in the United States. NCHS reported that approximately 8000 children under the age of 24 had acquired or congenital limb deficiency, approximately 4.3% of those surveyed having lower limb defiencies.

There are many problems associated with children and their prostheses that are not encountered by adults. Most of the prosthetic legs being used by children do not address the specific needs of the child, namely, affortability, durability, easily adjustable for the prosthetist, and active use. Current prostheses being used by children meet some of these requirements, but no one prosthesis meets them all.

The definition of pediatric prosthesis should be "a prosthesis designed specifically for children's needs"; however most prosthesis designers haven't recognized such needs. One of these needs is the reduction of cost associated with replacing prosthetic limbs and/or major components as the child grows. The inability to lengthen pylons as opposed to replacements is one of the main problems with current pediatric prosthetic legs that must be overcome to address this.

The NCHS study found that prosthetic leg users, under 24 years of age, pay out of pocket for 48.2% of the bills for a new prostheses. On average, a 7 year old child will need to replace his/her prosthetic leg at least once a year. Studies have shown a child's foot increases 21% in size between 1 and 5 years of age (1). The cost of a new energy storage prosthesis, a new socket, and any alignments necessary will cost between $5,000 and $7,500. A prosthesis with extendable pylons rather than replaceable pylons would significantly reduce the cost of the replacement prostheses.

There are a few prostheses made specifically for children such as, the Child's Play Seattle Light foot from M+IND, and the Pediatric Springlite II from Springlite. There are other prostheses on the market that children use, but none have adequately addressed the physical limitations and costs facing children in dealing with a prosthesis.

The main differences between an adult's prosthesis and a child's is the need for length extendibility, the reduction of replacement legs, and a light weight design. The Child's Play is a dynamic response modular foot made from Delrin II, a plastic composite. A dynamic response foot is one which returns a substantial amount of energy to the user which has been imparted to the foot. The Springlite II foot is made from 100% carbon fiber/epoxy. this foot is also a dynamic response foot. This foot is designed with custom toe stiffness, a heel which flexes and absorbes the shock, and a special adapter that allows the user 2.9 cm. of extension for growth.

There are a number of successful prosthetic designs which have been models for comparison of other designs to evaluate their success. The Flex-Foot is a modular prosthetic foot and leg designed with a continuous keel and pylon component (2), a design allowing the leg to be very flexible and to

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have a large capacity of energy return. The Flex-Foot is custom made, allowing for adjustable heel stiffnesses and configureations for higher cadence activities. A pilot study conducted using the Flex-Foot against other dynamic responce feet concluded that the Flex Foot foot gave users greater toe-off (ie. greater acceleration from the foot pushing off the ground) than others tested (3).

Another widely used prosthesis is the Seattle foot which has been used in comparative evaluations in many investigations. The Seattle foot is a dynamic response foot. The SACH foot is a Solid Ankle Cushion Heel design with very little flexibility. A Kinematic Analysis of the gait of children with b-k amputations using the SACH foot and Seattle foot showed that the energy storing Seattle Foot produced a small increase in stride length, which lead to an increased velocity (4). The SACH foot, which is a low energy storing device, provided no increase in stride length or increase in velocity.

A comparison was made of the Flex-Foot and the Seattle foot to test the energy storing properties of (5). The analysis was conducted with the subjects walking at a normal pace and ground reaction force patterns were collected. The results showed no asymmetry in reaction force patterns. All testing results showed few differences in the energy storing and energy return capabilities of the different designs.

RESEARCH GOALS

The goals of this research were: (i) To develop a modular, extendable pediatric prosthesis that would reduce prosthetic replacement costs. (ii) To design prosthesis which would both absorb energy and return that energy to the child during ambulation. (iii) To evaluate the feasibility of such a design by performing mechanical and metabolic energy tests.

METHODOLOGY

Research was conducted to determine the specific needs of users. An extensive literature review and patent search obtained all available information on existing products and new technologies implemented in prosthetics. In order to design the pediatric prosthesis with users' needs in mind, questionnaires of limb deficient children and their parents, interviews with local prosthetists, and observations of children with prosthetic legs were conducted.

The design of the prosthesis was developed through use of Quality Function Deployment, a method used to identify the intended users which would include input from the limb deficient child, the product designers and engineers, manufacturers, marketing, and sales.

The design of the prosthesis included sketches, 3-D models, engineering drawings, test models, a working prototype, and an analysis comparing the new design with the child's current prosthetic leg.

Sketches were made to describe the overall design of the components and to determine the final mechanism necessary to secure the pylons. Engineering drawings were made for 3-D sketch model fabrication, working determined the function of specific components, and Autocad drawings were created of the final design which were sent to the fabricators.

After the fabrication of the prototype, cyclic testing was performed to analyze the function of the design. A child was found to perform the necessary tests, which included a metabolic cost analysis and a mechanical energy test. With the assistance of a child with B-K bilateral limb defiencies their completition determine the performance of the device in comparison to the child's existing prosthesis which was a Flex Foot.

Mechanical Energy Testing

The first test performed by the child was the mechanical energy analysis. The child donned the new prosthesis on his right leg and performed the test. The child then replaced the new prosthesis with his/her current prosthesis and repeat the test.

A six camera VICON video motion analysis system acquired the motion data. Kinematic data was collected by placing markers at the hips, knees, ankles, and second metatarsal heads, as well as the mid-thighs, mid-tibias, heels, and sacrum. Ground reaction force data were as the subject walked at a self-selected comfortable speed (approximately 2.5 mph) across a 20 foot walkway with the force plates located in the middle portion of the walkway.

Metabolic Cost Analysis

The next set of tests performed on the child evaluated the metabolic cost analysis of the child while wearing each leg, and the results were compared. The child's metabolic cost analysis was performed with the use of a Medical Graphic CPX metabolic measurement system which measures the subject on a breath by breath.

Base line measurements were taken prior to the first test to determine the child's heart rate. The subject walked while wearing the new prosthesis, at approximately 2.5 mph, on a motorized treadmill for approximately 15 to 20 minutes. After the first test was completed the child rested to allow his heart rate to return to normal. The test was repeated with the child's current prosthesis.

The heart rate was recorded during the testing when the child reached his level heart rate. Oxygen consumption was measured during the testing using an automated expired gas analysis system. After both types of testing had been completed, the data was analyzed to determine whether the energy cost associated with each prosthesis were comparable.

RESULTS AND DISCUSSION

During the mechanical energy testing, each foot absorbed a similar amount of energy from heel-strike, but the obvious difference occurred with the amount of energy that was returned to the user at toe-off.(fig.1) The amount of energy the new design returned to the user was nearly twice that of his current prosthesis. This would indicate that the new design would be better for the child than the current leg.

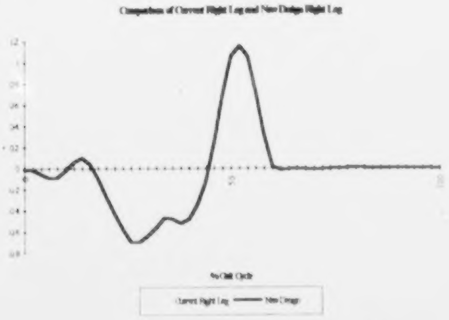

fig. 1

The metabolic cost analysis was then performed to determine if the initial assumptions made from the mechanical energy tests were correct.

The data comparison between the two tests show a slight increase in both oxygen consumption and carbon dioxide output while the subject wore the new prosthesis.

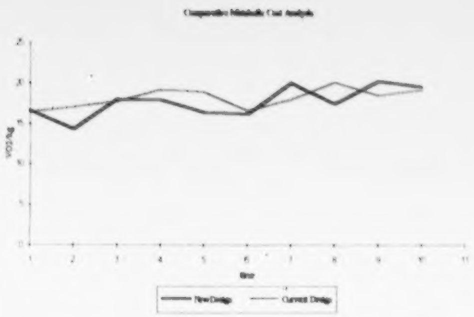

fig. 2

In conclusion, prostheses designed specifically for the pediatric population would reduce the costs associated with replacement prostheses. Thus, it is true that children who require a below-knee pediatric prosthesis will require fewer replacement prostheses resulting in a reduction in cost, because of the extension in length to compensate for the child's growth.

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PEDIATRIC THERAPEUTIC PLAYSTATION

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Abstract

The physical and occupational therapists at a local children's hospital wanted to incorporate multiple therapeutic activities into one area. The success of pediatric therapy hinges on the ability to motivate the child to participate in the therapeutic activities. The resulting design consisted of more than 25 different therapeutic activities disguised as a magical forest. The main structural items are a 12 foot swing, slides, parallel bars, a vertical ladder, and a tunnel and steps with a quiet area. The form of these functions includes a cave, a tree for climbing, a bridge, and two trees housing the swing. Since its completion in October 1995, the Playstation has seen patients dealing with fine and gross motory, sensory, cognitive, and cause and effect issues. The impact has been significant, in that, the speed of progress and overall success of the therapy for those patients has been directly improved.

Background

The theory behind the therapeutic activities for the playstation project can be categorized as motor, sensory and cognitive development. The motor skills therapy deals with the range of motion, strength against gravity, flexibility, and neurological control. Sensory therapy encompasses visual, tactile, hearing, and reflex issues as well as the experimental therapy being done with forming new control centers in the brain to interpret sensory inputs. For children who are non-verbal and have little control, the ability to demonstrate cognitive abilities becomes a great challenge. The basis of cognitive development and evaluation deals with cause and effect understanding.

Statement of Problem

To assist in the success of pediatric therapy, a multi functional area needed to be designed and built. It needed to encompass the range of therapeutic needs as well as address the challenge of pediatric therapy, namely motivating and stimulating the child.

Design

The design constraints of the project were to incorporate the different therapeutic equipment into a 15' by 18' ft area that was stimulating for the patients as well. The therapists provided a wish list of activities that they wanted as well as requirements associated with. Additionally, the hospital did not want this as permanent due to expansion plans. The Playstation equipment could not be attached into the floor, walls, or ceiling and needed to be able to be disassembled into discrete modules. Another crucial constraint was the budget. Because of the non-profit nature of the sponsoring organization, the budget limit was $2000 for the entire project. This made the cost of materials a top consideration.

Form and function played equal roles in the design, and they had to be considered at the concurrently, not sequentially. The design process was implemented to formulate the range of design options, and each option was evaluated for structural integrity, manufacturibility, cost effectiveness, and feasibility. Once the final design concept was chosen, it was taken through the quantitative process. This involved calculations dealing with structural integrity, strength of materials, and compatibility of materials in a hospital environment. The assembly drawing of the project can be found in Figure #1.

The idea of a magical forest not only transcended gender issues to appeal to all children, but gave children the opportunity to experience nature and to engage their own imaginations.

Development

The constraints for the project were developed through a cross-disciplinary team consisting of engineering students, medical professionals, an engineering faculty advisor, and the facilities engineer of the local children's hospital. The success of the team hinged on the clarity of the technology transferred from those with an engineering background to the medical professionals that would be using the project. To ensure consistent communication during the development, meetings were held on a regular basis. During the construction period the feasibility and cost of some materials required design changes.

Evaluation

The process of evaluation was comprehensive and extensive to ensure safety, durability, and structural integrity of the playstation for patient usage. The project was evaluated and approved at the preliminary design, proof of concepts, at several stages during the development, and a final review was completed by the hospitals facilities engineer. The project was designed with a safety factor of at least four for load bearing members such as the frame of the swing set or the weight holding capability of the cave. The safety factor was based on patient weight to accommodate the range of potential pediatric patients. The individual sections of the project were tested independently prior to final assembly.

The feedback from the therapists has included children's' response to the playstation, the improvement of therapy sessions, and the therapists' ability to use the playstation. The children have responded positively to many of the details, such as the cave drawings and the butterflies. The quality of therapy has directly improved as a result of the playstation. Therapists have found that the patients progress at a higher rate and are stimulated in a positive manner by the surroundings. Lastly, the therapists found that the mobility of many of the components allows them greater flexibility in accommodating the specific needs of different patients.

Project Breakdown

Swinging Tree: The foundation is a 4" x 4" steel tube frame. The trees over the frame so the patients feel like they are playing with swigs, ladders, hammocks, etc. that are suspended from a tree branch. The swingset was designed with 6 foot radius to accommodate the range needed for swings such as a wheelchair swing or a platform swing.

Climbing Tree: The concept behind the climbing tree was to encourage children to stand, support their body weight with their upper extremities, and provide for the opportunity to address coordination. The rungs are disguised as branches of the tree so that the patient has the sensation of climbing a tree.

Cave: The cave consists of three main areas: a quiet area, stairs with a railing, and a tunnel. The quiet area was developed to work on sensory issues and allow the child a safe and quiet place while in the therapy session. The stairs and uneven cave surface provide the child encouragement to work on balance, coordination, and standing or crawling. The tunnel and cave drawings provide the child a chance to explore in a nature-like atmosphere while encouraging hand-to-eye coordination and movement.

Water Pool: Hydro therapy is a very successful means of engaging a child in therapy. The water pool can be accessed by stairs or by standing. It allows the child to work on tactile and cause and effect understanding.

Slides: The playstation slides include one for a scooter and one for walking, sitting, or sliding. They are at different slopes and lengths to give the therapists a wider range of difficulty levels.

Parallel bars: The parallel bars are a common therapy item, but the combination of a bridge requiring stair climbing and a walking surface are unique to the playstation.

Sensory Items: The mural is not only visually stimulating, but was also designed to be interactive. The panorama of magical animals and scenes engages the child to focus, track, and encourages hand-to-eye coordination. The sensory area also includes a beaded wire system

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of varying shapes and colors. Throughout the playstation, the child can find, touch and smell flowers, butterflies, mushrooms and vines.

Acknowledgments:

The project was funded by the Case Engineering Service Group (C.E.S.G.) at Case Western Reserve University in Cleveland, OH.

The author is indebted to the director of C.E.S.G. Julie Grubaugh and faculty advisor John F.X. Daly for all of the support, patience, and love provided throughout the duration of the project.

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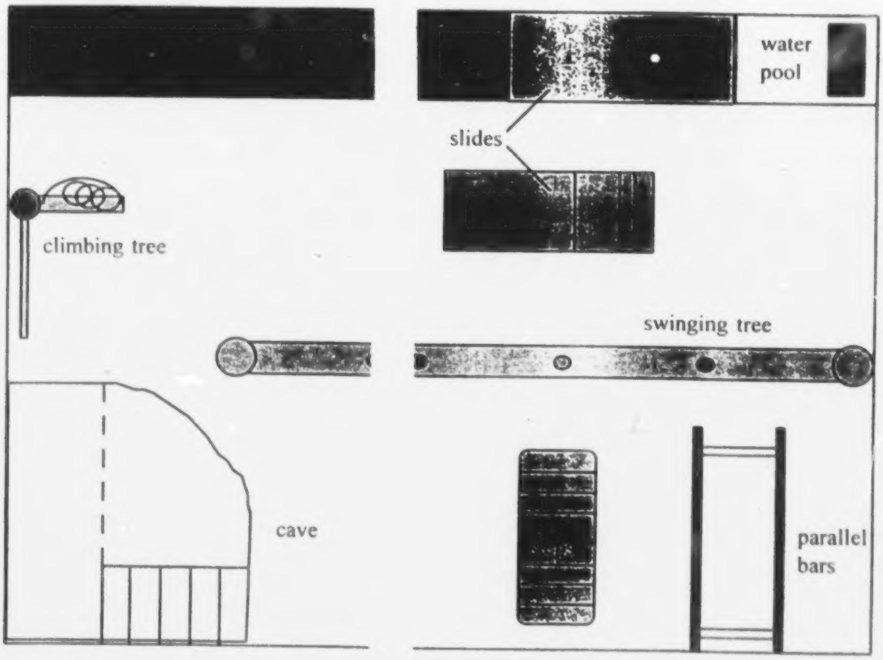
Figure 1



ART MAKING AND ASSISITIVE DEVICES

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ABSTRACT

This paper will describe several adaptive devices used by children with disabilities for art making. The adaptive devices were designed for the children through a grant project entitled: Opportunities for Children with Disabilities Art Making and Assistive Devices. An Art Therapist and Assistive Technology Specialist combine their efforts to provide the inclusive art making opportunities.

BACKGROUND

"Art is a fundamental human process. Every society, from the most primitive to the most sophisticated, has expressed itself through art".[1] Art is an important learning process for children, allowing them the freedom to explore movement, sensation and perception. And, when the process of art making, versus an objective endpoint is the goal, children have an opportunity to allow their minds to move freely.

For children with physical limitations, the ability to act on the instinctive appeal of art materials may not be possible due to the nature of their disability.[2] With the aid of assistive devices, however, children who previously may have been excluded from art making can enjoy the experiences that non-structured, non-judgmental, art making offers.

Opportunities for Children with Disabilities: Art Making and Assistive Devices, is a project that was started in 1995. The project provides art making opportunities for young children in inclusive classroom settings. The art making classes consist of approximately 6-8 children per group and is run one time a week, for one hour over the course of 6-8 weeks. Aiming to support inclusion the project provides adaptive art equipment for those children whose physical disabilities limit their use of commercially available art tools and changes to the art curriculum are introduced that will meet the needs of all the children.

This paper will focus on a three different adaptive art equipment designs involved in this project and the artists who use them.

RATIONALE

Most commercially available art materials require dexterous use of ones hands. This dexterity requirement makes it difficult for children with cerebral palsy and upper extremity involvement to use the art tools. When unable to use the art tools the children are excluded from the benefits that art making can provide. However, adaptive devices can provide a child access to art tools they previously may have been unable to use and allow the child to choose and experiment with different materials and colors.

DESIGNS

Design #1: Adjustable Easel Board with Turning Palette.

Here a young boy, five years of age sits at the same table as his peers even though his wheelchair will not fit under the table. The adjustable easel board clamps onto the table and is raised on a quick release bracket to rest over top of the boys wheelchair. This boy's arms are tight from tone making it difficult to grasp onto standard art materials (makers, crayons, craypas) and his reach is limited. Bulb holders make it easier for the boy to hold his art materials and a turning palette provides him independent access to seven different art tools where he used to have access to only one. As a result of this setup the child spends less energy in trying to grasp, reach for and use the art materials and where he used to tire after 15 minutes he now participates for up to 40 minutes.

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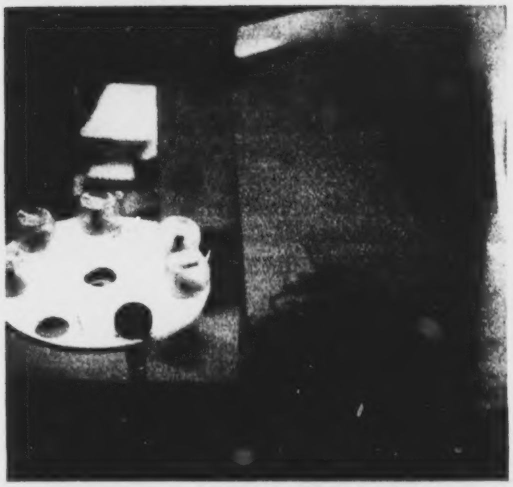
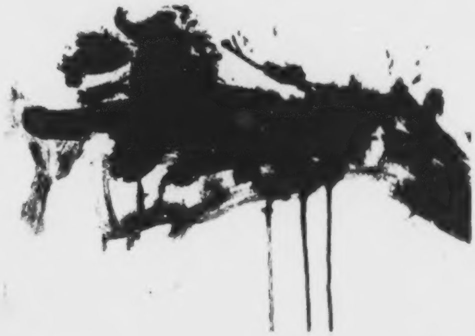


With his new set up this young artist brings to canvas his interest in dinosaurs and the color green.

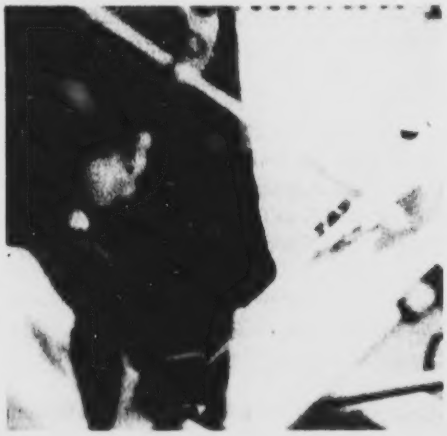
Design #2: Hand Strap Tool Holder. This five year old boy also uses an adjustable easel board and sits st the same table as his peers. He also has difficulty using his arms and hands because of tightness and tone in his upper extremities. A hand strap tool holder, similar to a universal cuff but adapted to fit a young child's hand and adapted to hold multiple materials, provides this young boy with increased freedom of movement.

When the child no longer must concentrate on holding the materials (increasing the tone in his arms) his shoulder and elbow are able to move about more freely. A paint palette C-clamped onto the art board in conjunction with a paintbrush, in the hand strap/tool holder, provides this boy access to six colors of paint he can choose at will. Prior to the use of this adapted equipment this boy was primarily a passive participant watching as others participated in art making.

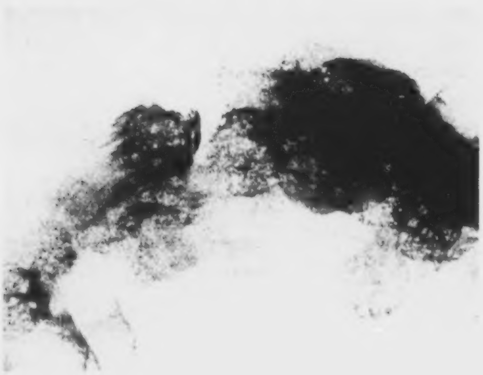
Now empowered with his adaptive equipment this young boy shows us his use of bold strokes and increased horizontal movement across the canvas.



Design #3: Hat Mounted Head Stick with Spring Component. The boy in this picture, A.S. is 14 years old. He has little active movement of his arms due to significant tone throughout his extremities. His head and neck, however, offer him the greatest and most controlled active range. To access this movement a hat mounted head stick was provided for him (a mouthstick was ruled out as an option as his oral motor control is limited, and his bite reflex would dominated). A Bulls cap was chosen for modification as A.S. is a dedicated fan of this basketball team.



The head stick utilizes the mouthstick appliance tips available from the Modular Mouthstick Kit (available from Therafin Corporation) for interchanging various paintbrushes, pencils and other art tools. To accommodate the changing distance the tip is from the paper when A.S. moves his head from the side and across the middle of his flat canvas a rubberband spring action component is added to the end of the headstick.



With his headstick and adjustable easel board A.S. brings to canvas his interpretation of "basketballs in motion".

DISCUSSION

Out of 75 children serviced over the past year through the Opportunities project 25 were provided adaptive equipment for use in inclusive art making groups. The adaptive equipment overall provided the children with disabilities increased independence in art making and a greater amount of choice making with colors and materials. The process oriented art making curriculum (versus an art curriculum based on a set end product), with an emphasis on exploration of materials and expression, provided success for all children involved.

For more information on the Opportunities for Children with Disabilities Project or for detailed instructions on fabrication of the adaptive art equipment designed for the children in this project write or call the author.

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TELEMENTORING AND COLLABORATIVE LEARNING FOR STUDENTS WITH DISABILITIES

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Abstract

The Science, Engineering, and Math (SEM) program that the University of Delaware is developing strives to increase the number of students with disabilities in SEM academic programs. Younger students are provided with field-based activities through summer programs which features inclusionary environments set within a science context. The mentoring program pairs high school students, with disabilities and an expressed interest in SEM fields, with mentors who are professionals in SEM related fields. The mentoring program is designed to make use of current technology and telecommunication tools - hence the name "telementoring".

Background

The University of Delaware's SEM program strives to increase the number of individuals with disabilities in SEM academic programs by focusing on the students, their families, educators, and (future) employers. The fact that individuals with disabilities are underrepresented in SEM academic programs and professions is well documented. There is, however, no inherent reason why individuals with disabilities cannot succeed in these fields of study and professions. Indeed, although underrepresented, many individuals with disabilities are successful SEM professionals. In order to increase the number of individuals with disabilities in SEM academic programs and careers, students must be provided with positive science experiences and professional role models.

In addition to students, the SEM program focuses on families, educators, and employers. These groups are brought into the process through educational lectures and workshops on topics such as assistive technology, legislative rights and obligations, disability awareness, and current medical/engineering research on disability issues. Students in the program are provided with positive SEM experiences through participation in extracurricular activities. For younger students, elementary and middle school age, these activities are inclusionary summer camp based. For high school students, positive SEM experiences and strong role models are provided through a mentoring program. This mentoring program not only involves students, but families and community members (mentors, and future employers) as well. This use of the Internet allows individuals to participate in the program from a wide array of geographical locations and work sites. Currently, the program enjoys tri-state participation (DE, NJ, PA) and individuals conduct their activities from either home, school, or work, depending on the site of their Internet connection. Thus, the summer programs and telecommunications based mentoring increases the students' interactions with other students, both disabled and non-disabled, and with professional adult role models.

Population

The target population of this research is composed of students exhibiting physical and sensory disabilities. Physical disabilities to be considered include spinal cord injury, cerebral palsy, muscular dystrophy, spina bifida, and other orthopedic disabilities. Sensory disabilities include blindness, low vision, deafness, and hard of hearing. The total number of students in both programs is currently 26, with an equal number of mentors. The mentors come primarily from professional and university environments and, in some cases, have a disability themselves. Currently, roughly half of the mentors participating in the program have disabilities

Telementoring

Mentoring is a process by which one person with specific experiences, knowledge, or skills shares their insights with another person who wishes to learn more about them. The traditional method of mentoring involves both face-to-face and more distant interactions between individuals. We will be using the term, "telementoring" to indicate that interactions between mentors and students which facilitated using telecommunications, primarily e-mail systems and telephones. This approach provides new opportunities, as well as challenges, for mentors and students as they engage in their ongoing relationship. In general, SEM mentors will work intensively with only one student but their names and areas of expertise will be entered into a common data base (the "mentor pool") which is accessible to all the students in the program. This allows for a generalized sharing of expertise when it is needed by anyone in the program over the course of the academic year. In addition, this approach allows small and large groups of mentor/student teams to efficiently engage in collaborative projects which require a common goal and shared efforts. The mentors have specific roles, with accompanying expectations, which will facilitate the development of their relationship. The roles to be fulfilled by mentors in the SEM program include:

- A willingness to share knowledge and skills in an area of science, engineering, or mathematics with one or more students
- A willingness, and the ability, to communicate at frequent and appropriate times with their student partners.
- A willingness, and the ability, to communicate at frequent and appropriate times with their student partners.
- Interest in learning more about the strengths and weaknesses of their student partners and the ability to use the information to guide/facilitate the development of their partners.
- Sensitivity to the challenges faced by persons with disabilities and a desire to understand and help the students overcome personal and academic barriers to their achievement and success.

In general, mentors are selected who provide their student partners with models of positive, professional performance; advice about problems, encouragement, clarification of future job goals, and a friendly, non-judgmental ear for their partners. Finally, there are three technological approaches to telementoring as it is practiced in the SEM program:

Eudora is used for e-mail communications between students, mentors and program staff. Eudora is a very popular type of software because it combines word processing and communications capabilities into a single application program. It allows you to write your message off-line using a built-in word processor. One a message is completed, the program then goes on-line briefly to mail it. It also uses an English-language set of commands that makes it easy to use and more understandable than many other communication software programs.

The Internet is used for **World Wide Web** access by students. The WORLD WIDE WEB (WWW) is a name given to a hyper-media protocol on the Internet that provides easy access to people, products, images, and new ideas. The WWW provides an easy to access, intuitive interface for many of the Internet's most powerful resources including Gopher, newsgroups, ftp, and most recently, e-mail. Through use of the WWW, students and mentors can efficiently access many resources and data at most universities, laboratories, governments and corporations around the world.

Videoconferencing is another virtual tool used to facilitate student/mentor/staff relationships. This is a relatively new technology which allows for two-way audio and video interactions. At this point, videoconferencing has been used to facilitate a large-group meeting of students and mentors and soon will be used to facilitate the development of "virtual classroom" interaction between SEM students and students from other classes throughout the world.

The results of the mentoring partnership should elicit both tangible and intangible outcomes for students and mentors:
1. Cooperative research projects involving both their student partners and other groups of student/mentor teams
2. Locating and accessing reference materials and information using libraries and Internet resources
3. Guidance concerning academic choices/decisions leading to greater exposure to science, engineering, and mathematics in school
4. An authentic relationship between students and professional scientists leading to mutual respect and understanding.

Activity Descriptions

The activities in the project can be categorized as 1) individual, 2) student/mentor, and 3) virtual class projects. Current projects include the following:

The "Internet Pizza Challenge". This is an ongoing activity in which student/mentor teams are provided a series of intellectually challenging questions developed by ASEL/SEM staff. These questions are all be answerable through creative use of the Internet and World Wide Web using search and discovery tools with the focus being on developing the students' search and problem solving skills.

"Make a Difference (MaD) Scientists!". This is an initial social/historical design project in which students and mentors select and then research the life of a distinguished scientist and then construct a Web page that presents their greatest achievements and what makes them different and special.

The Student/Mentor Yearbook. This project involves the construction of a yearbook of all SEM participants and the posting of it on-line for others to come to know all of the students, mentors, and SEM staff. Each student and mentor are designing and writing their own HomePages for placement on the World Wide Web.

On-Line Publishing: students will utilize their biographical profiles of esteemed scientists to produce articles for an upcoming issue of the electronic magazine called "Newsday" published by a group called the Global SchoolNet Foundation.

Career Development: as the relationship between mentors and student matures, there will be an increasing amount of attention given to providing students with appropriately timed information about colleges and other post-high school vocations in the sciences and technical fields. This information takes the form of career counseling, virtual "visits" and real visits to college campuses, and financial assistance programs.

"Science Talks to Us". A series of telecommunications events are planned that will allow for on-line interactions with scientists, politicians, writers, and educators in the area of science education and policy. An emphasis will be placed upon discussions with those persons who have made significant contributions to the development of policy and procedures of persons with disabilities.

Assessment

Student learning and motivation is being assessed as an integral part of the SEM program. There has been a sincere attempt to make the assessment process as unobtrusive as possible by embedding the assessment information within the activities so that they are a part of the structure of activities rather than isolated, and easily identifiable, events. *Performance Evaluations* are embedded in activities like the Pizza Challenge and MAD Scientists. The types of data that are gathered within these activities include: 1) the number of Ss responding, and 2) the quality of responses by the students. *Attitudinal Assessments* are done in a pretest and posttest manner and are part of the Yearbook and HomePage design activities. The information gathered in the attitudinal assessments include the students perceptions of science and scientists as possible careers, how they like to use technologies for communications and learning, and their perceptions of the mentoring process.

Summary

The SEM project is not a project that uses "technology for technology's sake," rather it is designed to provide students, who are relatively isolated and excluded from the scientific enterprise of the nation, a sense of community and direction. The intent of the program is to continuously assist and track these students through their high school, college, and early careers with the expectation that the success of the program will be evidenced by an increase in the number of persons with disabilities engaging in productive and rewarding careers in later life.

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BATTER UP! ASSISTIVE TECHNOLOGY FOR THE SPORTS ENTHUSIAST

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ABSTRACT

People with developmental disabilities are increasingly participating in activities often considered unavailable to someone with disabilities. Both moral consciousness and public statute have provided encouragement to end this inequity. One area that continues to receive little attention commercially is leisure, entertainment and amusement. This has been excused because recreation has been a luxury rather than a necessity. This product helps alleviate this lack while affecting several positive psychosocial enhancements. Batter Up! is designed to allow greater access to Tee Ball, a widely recognized sporting activity. By allowing people with disabilities to participate more fully, it facilitates inclusion, independence, normalization and socialization. Batter Up! can be adjusted to provide varying amounts of assistance, which encourages users to perform at their maximum capability. The bat can be propelled by a burst of compressed air, and guidance is provided for those who produce their own motion. The device uses a standard tee, bat and ball which allows use in existing leagues and games.

BACKGROUND

The Rosedale School is part of the Austin Independent School District. The goal of the school is to teach independence to students with disabilities who have been traditionally segregated and forced to rely on caregivers. The faculty consists of physical and recreational therapists as well as teachers and administrators. Recreational therapy has been supported as a means of teaching independent living as well as providing pleasurable activity.

The University of Texas at Austin offers a graduate level class in the mechanical engineering curriculum titled Product Design, Development and Prototyping. This semester, the class was also taught as a graduate level Special Education class titled Design & Problem Solving in Assistive Technology. Design teams consist of students from both of these disciplines as well as members of the School of Social Work. These teams have worked together under the guidance of a faculty team from all three departments. The course was created with the aim of teaching design methodology as well as increasing University participation in the community. The combination of disciplines and support of Rosedale School have provided for a wide range of design projects this year.

The Rosedale School already has a large selection of recreational and entertainment devices, but they are largely tailored for younger students. The faculty has requested a product which will be age appropriate for the older students, 12-21. Customer wishes that drive the design process are varied and numerous. Motor requirements must be simple. Sensory stimulation will increase motivation and provide reinforcement. Because this is not a commercial product, budget considerations restrict the allowable cost of manufacture. The device must be lightweight and easy to operate so that a single teacher may set it up and use it.

Students at Rosedale already play tee ball. Not only do they enjoy being out of doors, they benefit from socialization in groups and active participation. The current process requires intensive faculty participation to help the students grip, guide and swing the bat. Most of the students wait passively until the teacher swings the bat for them. This project seeks a low technology device that will alleviate some of these problems while providing for increases in therapeutic areas.

METHODOLOGY

This project follows a product design process documented by Pahl and Beitz. The first step of the methodology is identification of customer needs. The needs discussed above have been proposed by the prospective users defined as students, therapists and teachers. These needs are rated in order of importance and entered into a Quality Function Deployment Matrix (QFD). The output of the QFD is a list of engineering requirements ranked in technical importance and difficulty. Both of these are used to generate a refined function structure, which diagrams functional solutions to all of the requirements.

Next, the methodology includes brainstorming ideas for physical solutions to each function created above. The wide range of team member experiences allows for greater breadth of conceptualization. The solution principles are documented in a table called a Morphological Matrix. From this matrix, concept variants are generated by combining different principles. The concepts are compared in a Decision Matrix after completing feasibility studies. Each concept is rated against customer needs weighted by the rankings determined above. Different methods of propelling the bat include magnets, springs and jet propulsion.

The final concept variant is taken into embodiment. Any relevant structural and parametric decisions must be made at this point in the process. In this case, issues that require great attention are the power source, user interface, safety and aesthetics.

DESIGN

The final design is derived from an jet propulsion concept. Batter Up! stands alone next to a standard batting tee. A PVC pipe is fixed vertically within a three footed base. At the top is an aluminum frame stretching a wire taut. The bat is hung on a swivel hook suspended from the wire. This system provides the guidance of the bat for students who do not hit the ball consistently.

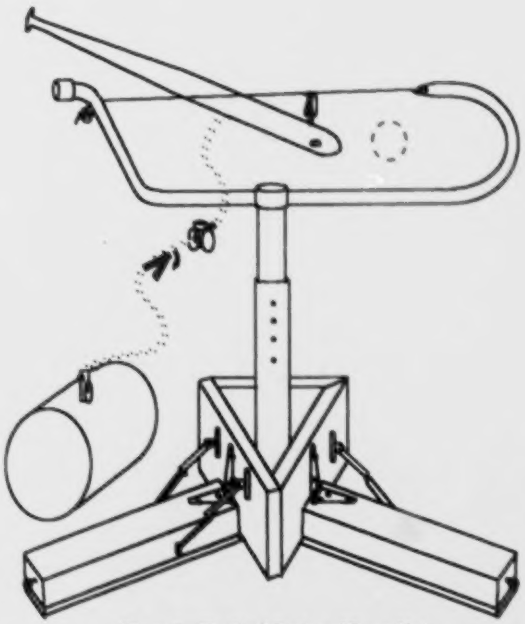

Figure 1. The Final Design of Batter Up!

An optional propulsion system for the bat is also available. A tank of compressed air sits next to the frame. A line runs through a regulator and hand operated valve to the bat. Inside the bat, a tube connects to a nozzle which protrudes through the wall of the bat. Activating the valve releases a burst of air which provides impulse to the bat.

Tactile stimulation is provided with several attachments to the bat. Various textures and sizes of cloth, paper, plastic and rubber can be added to the grip area of the bat. This also allows students who have trouble gripping a standard bat to interface with Batter Up!

Prototypes are built at several levels of sophistication in order to further refine the design. Batter Up! consists of two distinct design stages. They share a similar base and concepts, but differ in many parameters adjusted to better meet the customers' wishes.

Batter Up! includes a twelve gallon air tank which maintains pressure for more than 45 uses of the propulsion system. The first version, the alpha prototype, lacks easy actuation as well as capacity. The beta prototype incorporates a hand valve to allow operation from a standing position near the frame.

The frame is height adjustable in both stages. The guide wire on the alpha stage is fixed, but the second version provides the capability of adjusting the tension in the wire. The attachment to the bat, a snap hook that allows disassembly for transportation, is also more user friendly in the beta prototype.

RESULTS

The testing of Batter Up! at Rosedale School leads to several positive results for the design process. Batter Up! is used by students who apparently did not care to play tee ball before using the product. It improves the success rate for those who have trouble making contact with the ball. Another point that affects immediate student response is sensory stimulation. The flow of air through the nozzle makes a hissing noise that produces smiles and laughter from students.

The new design meets the customers needs in many regards. Inclusion, socialization and entertainment are facilitated by increasing student desire to play tee ball. Normalization is addressed because the design incorporates standard tee ball equipment. The new design reduces the burden on the teacher to activation and providing encouragement.

One of the most notable features of Batter Up! is the adjustment capability. Not only are the frame and grip system adjustable for physical considerations, but also the entire system functions with subfunctions disabled. The guidance system stands alone if the impulse is deemed unnecessary. This creates the opportunity for choice making and independence. If a student learns to play tee ball on his or her own, Batter Up! has excelled beyond expectations.

CONCLUSION

Through combining engineering design methodology and social work system perspective, the design for Batter Up! provides an attractive means of leisure and recreation to students who previously lacked options. The design creates therapeutic and educational opportunities for people with disabilities. These victories encourage further efforts in this area of rehabilitation therapy.

ACKNOWLEDGMENTS

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USING ELECTRONIC MEETING SOFTWARE AS A PLANNING TOOL FOR ASSISTIVE TECHNOLOGY SERVICE DELIVERY TO INFANTS AND TODDLERS

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Abstract

A focus group of infant and toddler service providers and administrators was convened to assist with statewide strategic planning for the provision of assistive technology devices and services in Maryland. The facilitator used electronic meeting software, or groupware, to capture participants' concerns as well as their proposed solutions to problems.

Participants were able to use several data formats to analyze the ranking of their top ten concerns. Subsequently they identified the role of each of the following in meeting their concerns: 1.) the Maryland Infants and Toddlers Program; 2.) their local jurisdiction's program; 3.) the Center for Technology in Education; and 4.) families. The results, efficiently gathered, can be utilized for program planning by all four groups.

Background

First in the nation, the Maryland Infants and Toddlers Program (MI&TP) began their assistive technology initiative in 1990 by contracting with the Center for Technology in Education to provide training and technical assistance. Statewide conference presentations, regional make it/ take it workshops, a summer seminar, and child-centered evaluation/training sessions formed the core of services CTE provided. Specific geographic regions were emphasized each year on a rotating basis to increase the depth of the training.

Electronic meeting software on a local area network is a recognized tool for decision support, originally used by the military and business. (1) (2) It is being used increasingly by the education community to improve decision-making and consensus building during school improvement team meetings and to build school improvement plans Electronic brainstorming provides a rapid means to generate a free flow of ideas as participants contribute simultaneously and anonymously. (3)

Objective

In 1995 MI&TP sought to evaluate the local state of the practice by soliciting information from local service providers and administrators. Their responses will help guide future planning in light of departmental reorganization and projected shrinking budgets.

Method/Approach

Invitations to the focus group were extended to persons or jurisdictions known to be providing services or with personnel adequately trained to provide such service if permitted/requested. Those who participated represented all four major geographic regions of the state. There were administrators as well as front-line service personnel, representing early intervention/ special education teachers, speech/language pathologists, and occupational and physical therapists. The parent perspective was also represented.

After introductory activities and an historical overview of the development of assistive technology services for this population, the facilitator posed the question electronically, "What are your major concerns about the provision of assistive technology devices and services to infants and toddlers with special needs?" Participants "brainstormed" independently on their networked computers. Responses were merged electronically into a master list of 24 items. Participants then ranked their top 10 most critical issues from the combined list. Items were subsequently sorted by rank sum, presented in descending order, and finally analyzed by number of votes in each rating. After discussion of the outcomes, participants were presented with the second major question, "What role do you see these providers playing in addressing your areas of concern?" Using another tool of the software called *topic commenter*, participants were presented with four electronic file folders to enter their opinions on the role of each of the following in meeting their concerns: 1.) the Maryland Infants and Toddlers Program; 2.) their local jurisdictions' programs; 3.) the Center for Technology in Education; and 4.) families. Through this tool, participants could not only identify potential solutions to their concerns, but could also identify the responsible parties from their perspective.

Results

The following were identified as the top 10 concerns (in descending order): 1.) insufficient funding; 2.) insufficient administrative support; 3.) limiting technology use to therapy time with insufficient follow-up across environments; 4.) the need for parent education to alleviate concerns about introducing technology at such an early age; 5.) interactive communication not being initiated early; 6.) insufficient training for family and school to use recommended equipment; 7.) computer technology not being introduced early enough for children with physical involvement; 8.) need for appropriate evaluation by trained personnel; 9.) need for more consultation between speech/language pathologists and educators; and 10.) insufficient time.

Participants perceived the role of the Maryland Infants and Toddlers Program in addressing these concerns to include: 1.) increase funding for devices, training for parents and professionals, and personnel 2.)recognize the time needed to prepare and provide A.T. services; 2.) establish better communication with all "players" to include clear guidelines with Part B programs to assure the continuation of A.T. services begun at the infant/toddler level; 4.) give good press to counties that show effective practices and offer incentive mini-grants to encourage the use of assistive technology; 5.) continue to use CTE to offer help/support/new ideas to the jurisdictions; 6.) work with the Maryland State Department of Education to establish regional CTE centers; 7.) provide jurisdictions with a list of persons qualified to do A.T. evaluations for this population; and 8.) evaluate whether the state's Tech Act Program is an effective resource in rural areas and make recommendations for improvement.

Participants perceived the role of the local jurisdictions' Infants and Toddlers Programs in addressing these concerns to include: 1.) consider assistive technology needs at every child's IFSP meeting; 2.) provide a "technology team" time to do evaluations; 3.) provide equipment with which to evaluate children; 4.) release service providers to attend inservice training; 5.) involve all aspects of the community (parents, families, school administrators, educators, local law makers) in education about the application of assistive technology to the infant/toddler population; 6.) house, circulate, and maintain devices for long-term loan; 7.) have a "bank" of software with site licenses; 8.) provide local funding support; 9.) identify sources of private funding for programs and families and assist them with writing grants; and 10.) document device use and success..Participants perceived the role of the Center for Technology in Education in addressing these concerns to include: 1.)provide trainings and make & takes for parents and professionals; 2.) travel to local jurisdictions to conduct evaluations of infants and toddlers; 3.) assist the local "techno-rangers" in the state by keeping them informed of new equipment, software, techniques, etc.; 4.) facilitate networking among local providers and administrators by holding forums to address constantly changes aspects; 5.) loan devices for trial use; 6.) help families seek funding for devices; 7.) conduct research and/or evaluation of device success/failure; 8.) consult on individual family and/or service coordinator's concerns; and 9.) make vendors and materials available to save local people time.

Participants perceived the role of families in addressing these concerns to include: 1.) become more proactive in establishing a forum for other families in their communities to become more involved in educating and empowering each other for ways to deal with issues concerning assistive technology; 2.) become as knowledgeable as possible by seeking information, attending meetings, seminars, etc.; 3.) be a part of the team: work as partners, not adversaries; 4.) use the strategies and devices provided to reinforce at home; 5.) take care of devices and return them in good condition at the end of a loan period; 6.) be open minded and flexible in considering options for the child; 7.) share concerns/breakthroughs with service provider and coordinator; 8.) lobby the state legislature for technology funding and 9.) seek means of acquiring devices they can own.

Discussion

Certain themes developed in all responses: the need for increased funding from multiple sources; the need for more training opportunities; the need for qualified evaluators; the need for a system for loaning devices; and the need to involve many "players" to assure the delivery of quality services.

Groupware helps groups communicate honestly and anonymously in a time efficient manner. In only a few hours participants were able to provide valuable information that can assist both the state and local programs in their planning. It is unlikely that traditional forums or surveys could have yielded the same results. Since each local jurisdiction received a Macintosh with modem from the state agency it is conceivable that future focus groups could be conducted without gathering the participants in a single location.

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MAKING MATHEMATICS AND SCIENCE ACCESSIBLE TO BLIND STUDENTS THROUGH TECHNOLOGY

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Abstract

Modern technology provides increased access to math and science educational instructional materials, media, and laboratory activities for blind students. Five projects supported by the National Science Foundation are described. Widespread use of these technologies would increase the math and science literacy of blind students and open new employment opportunities.

Background

Students who are blind are often counseled away from math and science courses even when their abilities and interests suggest that these are appropriate subjects for them to pursue. Little systematic effort has been made to provide access to science and math for blind students. The National Science Foundation (NSF) supports research and demonstration projects designed to enhance access to science and mathematics for students with disabilities.

Statement of the Problem and Rationale

Many employment opportunities today require mastery of math and science, and this requirement will increase in the future. Without opportunities to engage in these studies, students are denied important career options that should be available to them. Students with disabilities have been seriously underrepresented in science and math education and later in careers in these fields. Numerous blind scientists and engineers are currently successfully employed in their chosen careers. Personal creativity and assertiveness commonly were essential ingredients in implementing solutions to barriers they encountered, but use of adaptive techniques and technologies often provided needed accessibility. Documentation and dissemination of the techniques and technologies that enhance accessibility to science and math education for students with disabilities is needed. The following paragraphs describe five technological innovations that are increasing access to math and science for students who are blind.

Design, Development, and Evaluation

Access to mathematics. The six-dot braille code permits formation of 63 combinations of dots while higher-level mathematics is comprised of hundreds of different characters and functions. Standard braille notation for higher-level mathematics requires that multiple braille characters combine to represent most of these symbols. The presentation of equations commonly require several lines eliminating the possibility of retaining the customary, intuitive spatial layout of printed equations. Researchers have combined braille letters and numbers with raised-line math symbols preserving the spatial format of math equations(1). This technique, called "dotsplus," transforms the visual layout contained in an electronic document to a tactile layout. The dotsplus raised-line symbols are larger by a factor of approximately 2.5. These include most of the mathematical and scientific symbols. The document is printed by a modified wax-jet printer that produces tactile images, or it can be printed on a special "swell" paper using almost any standard printer. The swell paper is then heated causing the black portions to swell. Dotsplus documents cannot be printed directly from most computer files; they require use of high-level computer files. Dotsplus documents can presently be printed from LaTeX files and from some graphics-based word processor files. Dotsplus was first evaluated informally by over 50 blind scientists and mathematicians from around the world resulting in nearly unanimous endorsement of the technique. Additional evaluation is underway after advanced math textbooks were prepared for several blind students in dotsplus format. Widespread use of dotsplus will require availability of more math and science texts in high-level markup languages and the introduction of good quality, commercial wax-jet printers and/or lower priced swell paper.

High-level computer files can also be used to produce auditory displays of higher-level math equations. These computer files (produced by

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"markup" languages) contain "tags" that identify functions and **Making Science and Mathematics Accessible**

spatial layout of the file elements. Many publishers use these high-level computer files for preparing scientific texts. The AsTeR (Audio System for Technical Readings) computer program2 uses these files to present mathematical and scientific information to blind users through an audio format. The audio formatting presents the information and structure using both synthetic speech and non-speech sound cues. A listener can change how specific information structures are rendered and review them selectively by using many browsing commands. Efforts to port AsTeR to personal computers are nearing fruition. This combined with an increased availability of electronic texts marked up in La)TeX or other high-level computer language should permit widespread use of AsTeR by blind math and science students and professionals.

Multimedia presentation of the calculus. Mastery of the calculus is critical to students desiring to study science and engineering because it is fundamental to most advanced courses in these disciplines. The calculus often presents a serious barrier to blind students because the typical calculus course relies heavily on a substantial use of graphical components. Researchers are developing text materials and a multimedia environment to provide blind students enhanced access to the calculus(3). The project uses course content from a self-paced mastery course in calculus developed at Carnegie-Mellon University, and blind students use new multisensory media to present the course materials. Audio-tactile displays are prepared and programmed to be presented by the touch-sensitive NOMAD (TM), an audio-tactile tablet. Graphics are embossed on a soft plastic sheet that also contains a tactile grid. The more important details of the graph are presented in higher relief to give tactile expression to their varying importance. A round button is located at the base of each vertical grid line. When the button is pressed, the NOMAD verbalizes the x-coordinate of that line. Similar buttons are located along the left margin to identify the y-coordinates of the horizontal gridlines. A row of diamond-shaped buttons located along the upper right margin of the graphic announce associated key words from the text. Features on the graphic can be programmed to be spoken when pressure is applied to that location on the NOMAD's surface. Three levels of information can be programmed to be spoken. Blind calculus students are assisting in the project by evaluating the instructional materials at each stage of their development.

Three-dimensional tactile models. Three-dimensional computer graphics are now commonly used in many disciplines to display physical phenomena and mathematical data. Access to information displayed in three-dimensions has been difficult for blind students, and analogous tactile models have been difficult to produce. Recently, an innovative technique, laser stereolithography, has been used to produce tactile molecular models for blind chemists and chemistry students(4). This rapid prototyping process is used to produce three-dimensional plastic models from images created in computer aided design (CAD) programs. A computer-controlled laser is used to cure and solidify a light-sensitive, liquid polymer in a shape of an image produced by the CAD program. The process accurately produces intricate structures. Surface textures are modified to enhance tactual identification of atom types. Informal evaluation was first provided through regular use of the process by a blind chemist in his research. A more formal evaluation is currently underway in the Washington State School for the Blind.

Laboratory measurements. Independent measurement of laboratory experiments have traditionally been difficult for blind students. Since 1977, researchers at East Carolina University have attempted to develop instrumentation that would provide this independence for blind science students(5). Recent introduction of commercial science kits for school laboratories has simplified these efforts. Computers are made fully accessible to blind students with speech synthesizers, sound cards, and special software; and they become robust laboratory tools when connected to appropriate laboratory sensor probes provided in the new science kits. The East Carolina University researchers have now developed software that permits blind students to perform independent data acquisition and analysis for many types of scientific experimentation. Using a "talking, whistling, musical, large text laboratory work station," blind students can independently measure temperature, pH, mass, light intensity, distance, and properties of electrical circuits. Rising and falling pitches enable blind students to locate peaks and other qualitative features while the speech synthesizer verbalizes the quantitative measurements. Additional software programs are being developed that will provide independent performance of titrations, infrared and visible spectrometry, gas chromatography, and high-performance liquid chromatography.

Described video. Acquisition of the visual content on videos and films has always been a problem for blind "viewers." This becomes a potentially serious issue when the videos and films have an educational purpose. Auditory descriptions of visual scenes and activities traditionally have been available to blind people only from other viewers. For several years, the WGBH Education Foundation has been providing audio descriptions through its Descriptive Video Service (DVS) (R) on several dramatic series broadcasted by the Public Broadcasting Service (PBS). A three-year grant was awarded to the WGBH Education Foundation to study the value of describing science programs for blind viewers. The American Foundation for the Blind (AFB) conducted a rigorous evaluation of the value of audio description of science programs with over 100 blind viewers. Results of the study clearly demonstrated that blind viewers understand and retain information from science videos far better when audio descriptions are provided(6).

Conclusion

Modern technology is providing increased independent access to, and performance in, math and science education. Broad dissemination of these techniques and technologies should significantly increase the representation of blind students enrolled in science and math curricula and pursuing careers in these fields.

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DESIGN OF AN ASSISTIVE COMMUNICATION DEVICE FOR INDIVIDUALS WITH COGNITIVE AND PHYSICAL DISABILITIES

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ABSTRACT

Assistive technology is essential to improving the lives of individuals with disabilities. The development and implementation of assistive technology increases the capabilities of individuals with disabilities and their opportunities to participate in meaningful activities. This paper discusses the development of an assistive communication device, referred to as the "ACD" for students with severe physical and cognitive disabilities who have difficulty communicating with their environment. The ACD facilitates social interaction through the activation of pre-recorded messages and connections to other electrical devices. Furthermore, it stimulates the cognitive abilities of users via its implementation of two distinct configurations - a one button mode and a two button mode. Most importantly, the ACD empowers students with disabilities to make choices in their daily interactions with the environment.

BACKGROUND

The Rosedale School is a program within the Austin Independent School District which recognizes the importance of assistive technology in improving the lives of individuals with disabilities. A school for students with severe physical and developmental disabilities, Rosedale incorporates assistive technology into a functional and community-based curriculum implemented with the students. The utilization of assistive technology partnered with education is intended to prepare students with disabilities to live, work, and enjoy life in the community in a meaningful way [1].

The majority of students at the Rosedale School experience severe deficits in their ability to verbalize intelligible speech. This significantly limits their opportunities for social interaction and the development of relationships with others. Additionally, it impacts their sense of independence in that they are unable to verbally communicate their needs and desires when they choose to do so. Assistive communication devices can help combat these factors and empower the students to develop some control in this arena.

A number of assistive communication devices exist on the market today ranging from low end technology, such as picture cards, to high end technology, such as the Liberator^{tm} made by the Prentke Romich Company and costing $7,300 [2]. The multitude of devices available facilitates the utilization of assistive communication technology by individuals with a variety of disabilities. Due to the severity of the cognitive and physical disabilities experienced by the Rosedale students, low end technology appears most appropriate in meeting their communication needs.

STATEMENT OF PROBLEM

One assistive communication device that Rosedale has embraced for the majority of its students is called the BIGmack^{tm}, designed and manufactured by Able Net, Incorporated. The BIGmack^{tm} is a single button device, approximately six inches in diameter, that produces a user-recorded message when activated. The BIGmack^{tm} is actuated by pushing the button, and can be utilized by students with a wide range of physical limitations. The BIGmack^{tm} device is used with Rosedale students in all learning situations, both in the classroom and in the community.

While the staff at Rosedale like the BIGmack^{tm} and have observed marked improvement in the socialization and learning of the students, they feel the device is limiting in various ways. First, the cost of one BIGmack^{tm} is approximately $85. Because of limited funding, only one unit is allocated to each classroom. Ideally, Rosedale would like every student who exhibits a need for the BIGmack^{tm} to be provided with one. Second, the BIGmack^{tm} can only record and playback one message at a time. This limits its use in various environments and increases programming time. It also lessens the device's capability of serving as vehicle for cognitive growth.

A device slightly more advanced than the BIGmack^{tm} is the Speak Easy^{tm}, also made by Able Net, Incorporated. This device is too complex to use with the majority of Rosedale students. Therefore, the teachers and staff at Rosedale are interested in the development of a new assistive communication device able to match the physical and developmental levels of their students and challenge them to advance.

METHODOLOGY

To develop the ACD, a structured design process was adopted from the Ulrich and Eppinger methodology, Product Design and Development [3]. The methodology emphasizes the direct tie to customer requirements throughout the design process while providing a framework for concept generation and decision analysis. Because the design methodology intends to map customer requirements to the final product, it also traces a well documented path for review of the development process.

The process began with an assimilation of customer requirements from the faculty and students from the Rosedale School. The design team interviewed teachers to develop an understanding of potential applications, current technology benefits and limitations, and social and educational system parameters. Case studies were developed for specific students to create an ecomap model of their social system and a documented description of their educational and cognitive development climate. Faculty were then given the opportunity to rank their identified needs in order of relative importance. Data from the customer interviews was charted to a House of Quality (HOQ) matrix. The HOQ quantifies relative importance and relationships between the customer requirements in addition to benchmarking existing products. Technical importance of the requirement metrics, as output from the HOQ, provided direction for the development process.

A function structure was compiled as a tool for understanding the energy, material, and information flows through the smaller subfunctions of the device. To maintain the link to customer needs, the requirements were mapped as flows from which the device subfunctions were developed. By applying this need/flow mapping technique, the identified subfunctions, from which the design solution principles were selected, inherently served to satisfy the identified customer requirements. The methodology was extremely effective in translating the psychosocial requirements, which dominated the needs matrix, into technically solvable device functions.

From the functional description, a morphological matrix of solution principles was created. Solution principles are specific technical concepts which satisfy one or more functional requirement, i.e., a sound chip satisfies the function record message. Combinations of solution principles were generated to form alternative device concepts. Pugh chart decision analysis narrowed the field of potential concepts and highlighted specific solution principles as desirable for inclusion into the remaining alternatives. A weighted decision matrix was used to identify the final design solution. Evaluation of the selected concept, a rigid dual button device, against the customer requirements prompted the inclusion of an adjustability function into the design. With the final concept selected, an initial or alpha physical prototype was produced and reviewed with the customer contacts. Based on customer feedback and manufacturability requirements, modifications were made to the design prior to fabrication of the beta prototype. Modifications included removal of a voice activated switch to a separate device, replacement of hardwired logic circuitry with an externally programmable integrated circuit chip, and including the use of printed circuit boards to reduce wiring complication. The result of the development methodology is a final design that is equivalently priced to existing technology while offering significantly enhanced functionality allowing for increased user independence and cognitive development.

RESULTS

The final design is illustrated below in Figure 1.

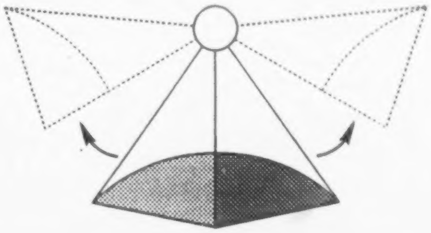

Figure 1: Assistive Communication Device

The ACD is ten inches in length and three inches in height at its tallest point. The ACD is angled as to accompany the internal electronics while making actuation of the device simple for students. The ACD can operate as a single unit, or can mechanically and electrically separate into two distinct yet connected units.

The ACD is programmed for different functions via switches located on each side of the device. As a single unit, the ACD can produce one of two recorded messages, as chosen by the user. When separated into two units, the two messages are divided according, one to each unit. This is especially beneficial for students with higher cognitive capabilities. Alternately, two students can share the ACD when it is set into two-message mode, each using a button to activate a unique message. The ACD is activated by pushing the yellow and red buttons atop the communication device. These colors were chosen because they are visually stimulating and attract the students' attention.

In addition to serving as a communication device, the ACD is able to "switch on" other electronic devices. Thus, when set in "switch" mode, actuation can start a blender, a radio, a fan, or other similar devices. Additionally, when properly programmed, one button can act as an assistive communication device and the other as a switch. For example, a student can activate one button to communicate the message, "My turn." The student can then activate the other button to turn on the blender. An outjack located on the front left corner enables the ACD to connect to other electronic devices. Additionally, an injack placed opposite of the outjack allows for a small switch, called a Jelly Bean^{tm}, to be "hooked in" to the ACD. The Jelly Bean^{tm} can be mounted to the head of a wheelchair and other locations to facilitate the use of the ACD by students unable to activate it with their hand.

An injack for a voice activation hook up is located on the ACD. This outlet gives teachers the option of attaching a separate component that would allow students to activate the ACD with vocal sounds as opposed to physical contact with the device. Initially, our team decided to build the voice activation component into the ACD, but later decided against it based on feedback from the customer upon presentation of the alpha prototype.

DISCUSSION

The ACD offers more options to the Rosedale students than the BIGmack^{tm}. Viewed as a "low end" technology appropriate for use with Rosedale students, the ACD is capable of storing multiple messages, activating other devices, and optionally being actuated by voice. The ability of the ACD to serve as a single unit or as two unit devices promotes its use with students who have a wide range of cognitive and physical disabilities.

The impetus for using a two unit option is significant. First, it provides students with an opportunity to choose between two messages or to activate both messages in a social interaction. Second, the two unit option allows students to generate a message and then activate an electronic device. Third, it facilitates the learning of cause and effect for students, promoting their cognitive abilities. Fourth, the two unit option encourages varying degrees of motor skill use since it can be adjusted to various degrees of separation.

The ability of the ACD to store multiple messages encourages its use in various environments. This is beneficial for Rosedale students who spend much of their school day in the community interacting with others and developing learned skills. Multiple messages as opposed to a single message can increase the duration of a social interaction and increase positive reinforcement for the student.

Additionally, multiple message capacity decreases the continuous programming currently required by Rosedale teachers and staff who use the BIGmacks^{tm}. Currently, the more greatly featured ACD costs an amount comparable to the BIGmack. This increases Rosedale's capability to provide an increased number of students with an assistive communication technology.

CONCLUSION

The development of the ACD for students at the Rosedale School is intended to enhance their interactions and learning in a multitude of environments. Additionally, the ACD enables the Rosedale students to exert some choice and control in their interactions. Empowering the Rosedale students in this capacity promotes their independence and self-concept which facilitates future social interaction and learning opportunities.

In an effort to secure the future production of the ACD for Rosedale students, the development of alliance between the Rosedale School and a neighboring high school in Austin is currently in process. The partnership will enable high school students who are enrolled in electronic and mechanical courses to replicate and further develop the device as part of their course curriculum.

ACKNOWLEDGMENTS

We express our gratitude to the Rosedale School for their commitment to improving the lives of students with disabilities and their interest in the development of a new assistive communication device by which to do so. Linda Lindamood, a speech pathologist at Rosedale, was instrumental in helping the design team understand the importance of socialization via communication for the Rosedale students and provided useful feedback throughout the design process. Also, a special thanks to the engineering, special education, and social work faculty who recognized the benefit of a multidisciplinary approach in designing assistive technology for individuals with disabilities and for their direction and support throughout the course of the project.

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SIG-07
Technology Transfer

TECHNOLOGY TRANSFER VIA INVENTION REVIEW: A PROGRESS REPORT

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ABSTRACT

In the past twenty-four months, the RERC on Technology Evaluation and Transfer received 1,600 contacts from inventors. Those contacts yielded 145 submissions, 90 product evaluations, and about twenty-seven devices deemed appropriate for commercialization. This paper reviews the program and assesses the contributions of a supply push model to the field of assistive technology.

BACKGROUND

The RERC-TET is one of sixteen centers funded by the NIDRR to advance the state of assistive technology research. This center is charged with soliciting inventions, refining promising prototypes and helping them become commercial products.[1] The assumption underlying this charge is that many useful products are already invented, but they are not available to consumers because they lack resources to move the invention to the marketplace. This assumption reflects a supply-push model --solutions exist and we simply need to push them out to meet and resolve problems.[2] Are there useful devices out there? Can public innovations meet consumer needs as well or better than focused research and development?

OBJECTIVE

To identify useful new assistive devices invented by researchers, companies and the general public, and provide the technical, marketing and consumer support needed to move them to marketplace.

APPROACH

How does the RERC-TET solicit promising assistive devices?

The RERC-TET first implemented a program for device prospecting -- a public information effort to promote the RERC's existence and mission. Device prospecting involves dissemination activities such as professional conference presentations to academic, professional practice and private-sector research and development audiences: presentations and information distribution at trade shows; mailings to manufacturers, distributors, and value added retailers; service providers through professional organizations, and agency and consumer networks nation-wide.

The RERC-TET is continuing an active campaign to solicit prototype assistive devices. Following a suggestion by our National Advisory Board, we obtained the national listing of patent attorneys, and mailed first to a national sample, then to targeted geographic areas. We also obtained information on the SBIR grantees for the agencies most directly involved in assistive technology (USDE, HHS, NSF) and mailed inventor brochures with an introductory letter to SBIR winners.

The Independent Living Center translated the consumer recruitment brochure into Spanish and then to other languages for dissemination locally, and through our state and national network of testing centers. To reach individuals from minority backgrounds, we mailed invention solicitation brochures to all the traditionally Hispanic and historically Black colleges and universities in the nation. The U.S. Department of Education furnished these lists at our request.

We are expanding our supply-side solicitation for inventions. Most companies in this field receive a continuing stream of unsolicited devices. We are offering to receive and screen those unsolicited inventions. This relieves companies from having to respond to inventor contacts, and they will have the first right of refusal over any devices that we determine might actually be of interest to that company. Further, most companies have devices in-house which have promise but are not being developed because the company lacks sufficient resources to pursue them. We are offering to develop such devices through joint arrangements, if consumers view those devices as worthwhile, with the company's assurance that they will market what we develop.

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How does the RERC-TET intake and review devices submitted by inventors?

Upon our initial contact with an inventor, we mail the inventor our eight page Device Intake Package. The inventor is instructed to complete the package and return it to us along with photographs or a videotape of the subject invention. We then undertake our initial evaluation composed of the following:

* **Documentation/Paperwork Review** - Is the DIP completed properly and signed? Did we receive enough graphic and visual information to perform an initial evaluation? Does the device fit the legal definition of an assistive device?

* **DOSABLE/ Literature Search for Similar/Competing Product**- DOSABLE, literature and catalog searches are commenced for competing/existing products in the marketplace.

* **Additional Information**- Is there an obvious ownership problem? Does the device infringe on an existing patent as detailed in DIP submission? What specifically is the inventor seeking from us? R&D, Business Plan, Clinical Trials? If the device is rejected, correspondence to inventor is generated with the reason for rejection given.

* **Initial Device Concept Review**- An internal expert affiliated with the Center for Assistive Technology is asked to spend approximately one hour reviewing the submission. They are asked to fill out a device evaluation form and give a brief written synopsis of their views on the device. If the findings of the Internal Expert are positive, the device then goes on to the Standing Committee for a more in depth review. If the findings are negative, a rejection letter is sent to the inventor detailing the reasons for the rejection and returning all submitted materials.

* **Standing Review Committee**- A representative from the Technical, Consumer, and Marketing teams identifies the problem/need the device addresses and the potential users/market for the device. Each person spends about three hours reviewing the submission, speaking with experts in the field, and generating a written report with his/her recommendation. The members then meet, exchange reports and discuss the merits of the device. The committee then makes a recommendation for or against commercializing the device.

* **Coordination Team Review**- The Coordination Team (directors of the three organizations operating the RERC-TET, the project coordinator and the director of commercialization) review the Standing Committee's recommendations. The team decides whether to offer an Agent Agreement to the inventor, reject the device as inappropriate, or to table the device pending the resolution of a specific issue. The decision and copies of all prior reports are sent to the inventor. If the findings are negative, a rejection letter is sent to the detailing the reasons for the rejection and returning all submitted materials. If the findings are positive, the device is passed on to our Director of Commercialization. He enters into negotiations with the inventor to allow Aztech to become the inventor's agent to seek a commercialization partner for the device.

RESULTS

How successful has the program been?

The invention solicitation effort (with over 21,000 brochures distributed) described earlier has yielded outstanding results. In the original proposal, our forecast for the first two years was about 500 contacts, about fifty submissions, twenty devices passing our review, and between ten and twenty moving to the marketplace. In the two years since the program's inception we have received over 1600 telephone, mail or electronic inquiries. Out of those we have determined about 475 callers actually have had prototype assistive devices and we have sent out 447 Device Intake Packages. To date, of those 447 packages sent out, 145 have been returned by inventors as submissions.

The majority of these device submissions are rejected in our initial screening process. Rejection reasons vary from existence of a competing product unbeknownst to the inventor, to technical unfeasibility, to existence of other technology that performs the same function, to not being an assistive device, to the almost non-existence of a market for a potential product. However, 27 of the 145 (19%) device submissions have passed our evaluations. Some of these devices represent an innovative new application of technology to meet an unmet functional need. Other devices are designed to meet needs already met -- but poorly met -- by products in the marketplace. In some cases, we find the prototype device offers functional value to a selected sub-group of the target population. Inventors of devices recommended for commercialization receive an offer from the RERC-TET to function as their licensing agent.

TECHNOLOGY TRANSFER

Nineteen of the 27 inventors who were offered an agreement by the RERC-TET accepted. Of those 19 products, three have been licensed to outside companies. Ten devices are currently being reviewed by companies which have shown an interest in licensing the devices. Four inventors took our device evaluations and referral information, and elected to commercialize their devices without a formal contract with the RERC-TET. The other devices have had their agreements terminated due to technical problems, companies offering licensing agreements not meeting the high expectations of the inventors, and no interest being shown by outside companies.

DISCUSSION

There is a basis for the assumption underlying the supply-push model. There are indeed useful devices languishing as prototypes, and with the appropriate supports, they can become commercial products. Based on our yield of about twenty viable devices from 1,500 contacts and one hundred evaluations, a supply-side model requires tremendous effort to sustain a flow of devices. The number and quality of device submissions may increase as the RERC-TET becomes better known and develops credibility through successes. We are continuing our work to that end.

What else can be done to improve the quality of assistive devices available in the marketplace? A demand pull model represents another approach. This model assumes that new devices are best developed by starting with the problem, not with a solution. Demand-pull identifies consumer needs and designs those needs into new or improved products. The RERC-TET's consumer-driven evaluation does implement a demand-pull process, once a product enters our process.[3]

To increase the influence of consumer demand-pull on the device commercialization process, the RERC-TET has implemented several new activities. For example, we are working with the network of State Tech Act programs and with our existing network of Centers for Independent Living, to develop a "ten most wanted" list of needed assistive devices. We have already defined consumer criteria for the dozen device categories needing improvement, so we can quickly apply those criteria to the devices identified through this process.[4] These devices then represent new devices available for commercialization, which have been defined by device users. This demand-pull process verifies consumer interest and market viability, key factors for successful commercialization. We will report the demand-pull results in the literature.

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A RETROSPECTIVE STUDY OF THE USE AND ABANDONMENT OF ASSISTIVE DEVICES DEVELOPED BY STUDENT DESIGN PROJECTS

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ABSTRACT

Our institution requires that all students complete a major design project. Working in groups of 2-4 during the senior year, the students usually devote approximately one third of their time to the project. Over the past 6 years, these projects have produced 15 assistive devices which were then used by either children or young adults. A survey of the use and abandonment of these devices showed that student designed devices exhibit similar reasons for abandonment when compared to devices obtained through other means. In addition, the study revealed a need for follow up testing and design modifications after the student design team has left, particularly with more complex devices.

BACKGROUND

At our institution, student design projects that develop assistive devices have two primary goals: providing a capstone design experience for senior engineering students and providing customized assistive devices to disabled users. The educational objectives and operation of the program have been described in detail elsewhere (1). Briefly, all students are required to complete a major design project. The project is usually selected at the end of the junior year and begun in the senior year. Working in groups of 2-4, the students devote approximately one third of their time during the nine month academic year to the project. Thus each project represents the result of up to one person year of effort. Since 1989, we have used these projects to design and develop devices to assist disabled individuals. A project is not considered successful unless a working device is conveyed to a specific individual (client). The costs of materials and components used to produce the devices were supported by grants. The clients received the devices at no cost.

Assistive devices developed by students represent a microcosm of the overall assistive device delivery system. Abandonment of assistive devices has been identified as a major problem in the delivery of services to the disabled and represents an inefficient use of resources. Factors that have been linked to device abandonment are: lack of user involvement in selection, easy device procurement, poor device performance and changing user needs (2). Developing custom assistive devices through student design projects mutually benefits the students and the clients (1). We were interested in determining whether there were unique issues associated with the use of student developed devices and whether the pattern of abandonment of these devices differed substantially from that reported in the literature.

OBJECTIVE

The goal of this study was to monitor the use and abandonment of assistive devices produced by major student design projects over an extended period of time. This would allow us to identify problems with past designs that could be used to improve the delivery of student developed assistive technology. In addition, detailed case studies developed from this study can be used in educating students on factors affecting assistive device usage.

METHODS

A survey was conducted in November 1995 to establish the status of all assistive devices developed through student design projects over the past six years. A standard data sheet was used to gather information about each device. Data were gathered concerning the current status and the length of time frame the device had been used. If the device was not currently being used, the reasons for that status were noted and a determination of the modifications or repairs necessary to return the device to use was made. Since all but one of the devices were developed through collaboration with a single residential rehabilitation facility, it was relatively easy to obtain detailed information regarding the use of each device. Many devices were still located at the facility. In cases where the clients had left the facility and taken their devices with them, staff at the facility were still aware of the device status.

RESULTS

During the past 6 years, 15 projects involving 46 students have yielded working prototypes (Table I).

Table I. ASSISTIVE DEVICE PROJECTS

Date Completed	Device	Current Status	Length of Service	Problems
1990	Wheelchair Lift	Abandoned	3 months	Heavy, bulky Limited access to client while on lift
	Athletic Standing Assist Device	Abandoned	1 month	Bulky, limited application, not useful for client
1991	Child Mobility Device	Abandoned	6 months	Required extensive training, noisy, rough ride
	Lightweight Wheelchair	Lost	Limited	None
1992	Art Class Assistor	Not In Use	2 years	Original client graduated, need new client
	Swingaway Laptray	In Use	3 1/2 years	Required minor repairs
	Reacher/Gripper	Not In Use	3 months	Required major repairs, no staff time
1993	Universal Arm	In Use	2 1/2 years	None
	Quick Release Push Cart	Not In Use	1 year	User lost interest, application modified Needs new client
	Therapeutic Tricycle	Not In Use	1 1/2 years	Outgrown
1994	Mobile Bow Mount	Not In Use	1 1/2 years	Must be modified for client's new chair
	Secondary Joystick	Not In Use	0	Required immediate modification, awaiting mounting
	Bowling Machine	Not In Use	2 weeks	Required modification, needs repairs, lack of staff training
1995	Shock Absorbing Foot Rest	Not In Use	2 weeks	Too bulky, compromised foot position
	Wheelchair Roller Exerciser	In Use	6 months	None

Three of the devices (20%) have seen continuous service and are presently in use. The universal arm which is used for holding cameras and similar items and the wheelchair roller exerciser have not needed any repair. The swingaway laptray initially required some minor modifications, but has since functioned reliably for over 3 years.

Four additional devices (27%), not presently in use, fulfilled their original purpose for more than one year. In each case, a change in user conditions or needs resulted in the use being discontinued. The therapeutic tricycle was outgrown; the client for the art class assistor graduated from school. The user of the mobile bow mount has a new chair, requiring modification of the device. The quick release pushcart was designed for transporting dishes in the user's residential setting. The original user lost interest in performing this task, and the device was modified for an alternative use. It is now awaiting use by a new client. Each of these devices could be modified to allow for continued use with either the same or a new client. These modifications would need to be performed by the staff of the rehabilitation facility.

The reacher/gripper, a motorized robotic arm, was initially successful and extensively used. However, it proved to be a high maintenance device. Major modifications were undertaken but not completed.

Three early devices (20%) were abandoned within 6 months due to a combination of poor performance and a lack of client/staff/caregiver acceptance. In addition, three recent devices (20%), the secondary joystick, the bowling machine and the shock absorbing footrest, are not presently being used due to problems associated with insufficient testing during development and a lack of adequate client/staff training. These devices experienced almost immediate mechanical problems when placed in use as well as some lack of acceptance by client/staff. The shock absorbing footrest also exhibited poor performance, in part due to lack of time for design modification by the student designers.

One device, the lightweight wheelchair, met all of the original design and client expectations but was lost to follow-up when the client moved.

DISCUSSION

Most factors affecting the use and abandonment of student designed assistive devices parallel those published for assistive technology devices as a whole (2). We deal with a young client population (ages 3-20) who are primarily in a residential setting. In this age group, it is to be expected that changing client needs, often associated with growth and maturity, will lead to discontinued use of many devices. Four of our devices were used for over 1 year before being discontinued. These devices met their original intended use and are considered to have been successful. Thus 47% (7/15) of the devices were successfully used.

Three early devices (20%) were abandoned within 6 months. The lack of success in these early devices is mostly attributable to our initial lack of experience in the assistive technology area. In executing these designs we failed to give appropriate attention to the user interface and to continued involvement of the client/staff/caregiver in the design process.

However, four well designed devices seem to suffer from problems specifically related to using students to design and build relatively complex assistive devices. Completion of the project is a requirement for graduation. If problems are encountered in executing the project, the time originally allocated for testing and evaluation generally shrinks sometimes to as little as 1-2 weeks. This has proven to be inadequate for several of the devices. The reacher/gripper functioned well for about 3 months, then it became apparent that some of the components were not durable enough for continued use. Major repairs were initiated by the rehabilitation facility but never completed. The secondary joystick worked but not well enough to suit the client. It appears that several iterations of minor modifications will be needed before the device is acceptable to the client. The rehabilitation facility has difficulty budgeting time for these activities. The bowling machine required substantial redesign by other students. The shock absorbing footrest also needs design modifications. In particular, the more sophisticated or complex electromechanical devices are more readily abandoned due to issues related to insufficient testing, maintenance or training of staff.

Within the limits of one academic year, student projects rarely proceed beyond a second design iteration. Several of these devices need a third or fourth design iteration, often to address issues associated with long term service. To improve the success rate of complex student designed assistive technology, academic institutions can chose only to work with rehabilitation institutions that can take on device repair and accomplish the additional design iterations or be prepared to take on these functions themselves using laboratory assistants. We are experimenting with the latter approach. To increase device utility, we now retrieve devices that need repairs that can not be readily accomplished at the rehabilitation facility. In addition we plan to modify some devices which no longer meet the needs of the original clients due to growth, changes in ability etc. so that they can be used by others. By experimenting with these approaches we hope to increase the utility and effectiveness of student designed and developed assistive technology.

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CONSUMER EVALUATION OF POWERED FEEDING DEVICES

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ABSTRACT

The project described here was formulated to evaluate commercially available powered feeding devices. This project was carried out by the Rehabilitation Engineering Research Center on Rehabilitation Robotics of the University of Delaware and the A.I. duPont Institute in Wilmington, Delaware, in collaboration with the Division of Rehabilitation of the A.I. duPont Institute. The study began in October of 1994 and the subject training and evaluation was recently completed in October, 1995. The discussion and results portrayed in this paper represent preliminary results of this project.

INTRODUCTION

Many individuals with severe manipulation disabilities require assistance with the task of eating. Because of its primary importance in a person's life, much effort has been exerted to design a robotic or automated device to aid individuals to eat independently. Although some devices have been fully developed, and several have become commercially available, there has been little acknowledged success in providing individuals with a powered feeding device {1}.

This project has identified three commercially available powered feeding devices (as shown in Figure 1): the Beeson Feeder, manufactured by Maddak, Inc. of Pequannock, New Jersey, the Handy 1, manufactured by Rehab Robotics, Ltd. of Staffordshire, England, and the Winsford Feeder, of Winsford Products, Inc. of Pennington, New Jersey. Each device operates on a similar principle. A mechanical arm is controlled by the user to scoop food from a desired section of a plate. The food is then presented to the user at a suitable height.

MOTIVATION

Although powered feeding aids have been available for approximately ten years, a small percentage of the user population utilize them, and few Rehabilitation Specialists are trained to prescribe them. Criticisms of the devices vary widely, but no formal evaluation of powered feeding devices has been carried out.

Because of the lack of published information about the efficacy of powered feeding devices, the project staff carried out an informal phone survey of 12 Occupational Therapy Departments from major rehabilitation hospitals throughout the USA. Table 1 summarizes the questions asked in the survey and the responses obtained. The totals provide a gross indication of the number of patients being served by the institutions. It is striking, however, that almost every institution reported that none of their patients use of powered feeding devices. Each institution was also asked to provide an open-ended comment on their use of powered feeding devices. The comments generally indicated that the available feeders are too expensive, too difficult to use, unreliable, inconvenient, difficult to transport, unattractive, and time-consuming to set up. Several institutions had not used powered feeding devices at all.

EXPERIMENTAL DESIGN

The experimental design was guided primarily by the desire to provide subjects with the opportunity to use the feeding devices in the environment in which they normally eat their meals. Information was obtained from the subjects through two mechanisms, a log sheet, which recorded the use of the devices in the home or institutional setting, and questionnaires, which were administered to both the subjects and the subjects' assistants. The questionnaires were administered after the use of each device and recorded the subjects' and assistants' ratings of various criteria of the machines. Presentation of the devices to the subjects was balanced to reduce bias.

TABLE 1. SUMMARY OF PHONE SURVEY

QUESTIONS	TOTALS
How many rehabilitation patients were admitted to your facility in 1993?	approx. 4150
Of those, how many were completely dependent for their eating needs?	approx. 920
Of those, how many were assessed for ability to use a powered eating device?	approx. 57
Of those, how many actually use a powered eating device?	3
Do you have a standard protocol that governs assessment for use of a powered eating device?	NONE

Figure 1. The Beeson Feeder The Winsford Feeder The Handy 1

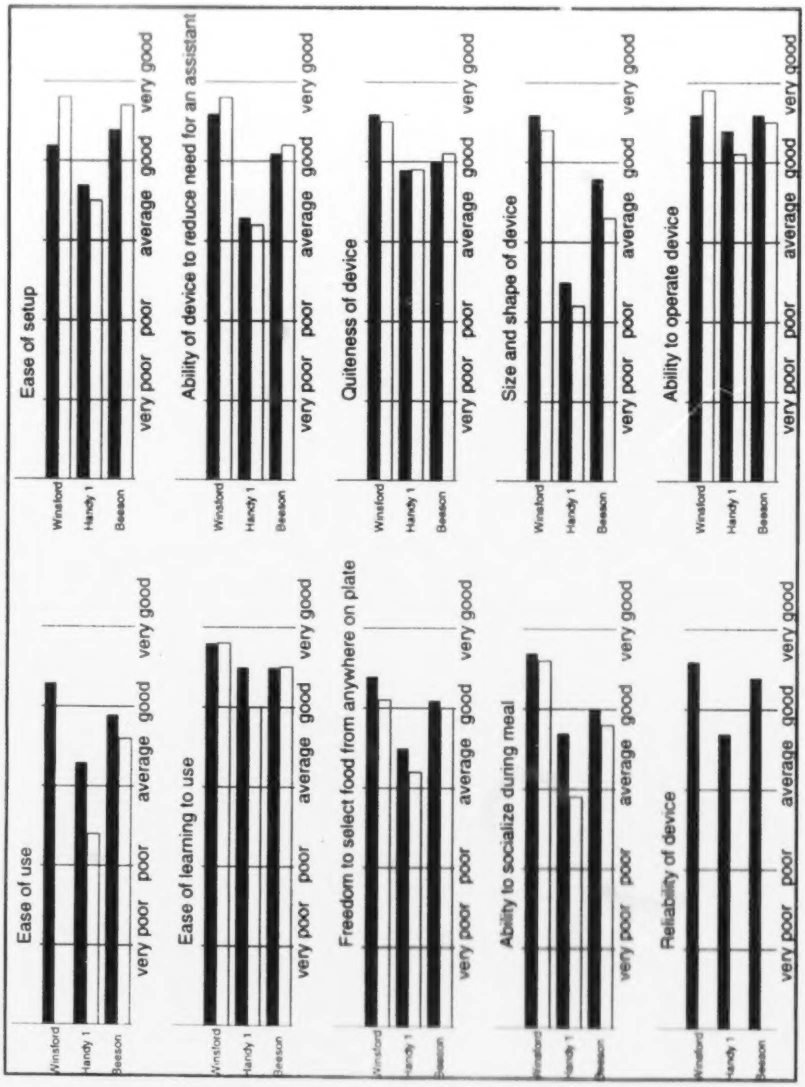

Figure 2. Bar graphs indicating both subject and assistant responses to the questionnaire. The dark bars represent subject responses and white bars represent assistant responses. Where no bar is given, further data reduction was required.

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SUBJECTS

Subjects for this study were identified through the Institute's Department of Occupational Therapy and through a mailed solicitation to local schools and rehabilitation facilities. Disability groups represented by the 12 subjects included cerebral palsy and arthrogryposis. Several candidates were not entered into the study due to a lack of sufficient head and neck stability. The subjects ranged in age from 9 to 40 and were split roughly 60% male and 40% female.

RESULTS

Compilation of the log sheets reveals that the results obtained are based on approximately 110 uses of the devices, totalling almost 90 hours in feeding time. Average meal times were roughly 33 minutes for all three devices, with set up and clean up time averaging under 5 minutes for all devices. On average, each meal required 1.8 interventions by an assistant.

Only preliminary results are provided here based mainly on the feedback acquired from the questionnaires administered to the subjects and their assistants during the evaluation sessions. Figure 2 shows bar graphs which compare the subject and assistant results across each device (the questionnaires administered to each group were the same). The dark bars represent the average response of the subjects and the white bars represent the average response of the assistants. In cases where the assistant information is missing further data analysis is required.

Further information will be forthcoming after the data analysis is completed. In addition to the results shown here, information was also obtained regarding the subjects' and assistants' relative rankings of the devices. Subjects were evaluated by the Occupational Therapy staff of the project. Some preliminary observations have indicated that some of the subjects exhibited an improved sense of self-esteem, improved lip closure, and improved posture after the two day home use, which corroborates earlier findings [2].

The complete results of this study will be compiled into a series of technical reports. In addition to a general report, each manufacturer will be sent a report which specifically highlights the strengths and weaknesses of their product as revealed during the period of the study.

DISCUSSION

It was generally found that the subjects both enjoyed using the feeding devices and found them relatively easy to learn how to use. Although Figure 2 provides some relative measurement of the subject preferences across devices, in almost all cases, the subject and assistant impressions were above average. This somewhat contradicts the phone survey responses discussed earlier.

Although no record of how long an intervention lasted, it was generally found that these lasted less than a minute. It was found then, that, on average, subjects were able to eat independently for up to one-half hour.

Based on the subjects who were not admitted into the study, it was found that the current feeders are less suitable for individuals with high-level spinal cord injuries or advanced muscular dystrophies. In both cases, the barrier for the subject was a lack of stable head and trunk control.

CONCLUSIONS

Based on the usage statistics in this study, it is believed that powered feeding devices could play a larger role in supporting people with severe manipulation disabilities to eat more independently. Each device was found to have its own strengths and weaknesses. It is hoped that communication of this information to the manufacturers will assist in improving future versions of the devices. It is also hoped that the data in this study will lead therapists and physicians to prescribe feeding devices.

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DIGITAL LOGIC CONTROLLED ELECTROMECHANICAL LONG LEG BRACE

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ABSTRACT

Long leg braces are prescribed for those incapable of ambulation due to quadriceps insufficiency or paralysis. These design lock the knee joint and require the user to adopt an unnatural and energy inefficient gait. A self-contained electronically controlled brace system has been designed and tested which allows knee flexion during the swing phase of gait, but restricts flexion during the stance, or weight bearing, phase . Laboratory test results comparing this new brace system and a standard locked Knee-Ankle-Foot-Orthosis show that knee flexion/extension kinematics are improved and that oxygen consumption rates are reduced.

BACKGROUND

The 1992 National Health Interview Survey reported that there were approximately 1,461,000 cases of lower extremity paralysis in the United States (1). Of these 186,000 individuals use leg braces (1). The need for knee braces may be created by paralysis of a leg caused by nerve or brain injuries, poliomyelitis, muscular dystrophy, or congenital defects. These individuals are often prescribed Knee-Ankle-Foot-Orthoses (KAFO's), also known as long leg braces. KAFO's lock the knee for ambulation and thus provide maximum joint stability. However, a locked knee imposes upon the user an unnatural and energy inefficient mode of ambulation.

Many attempts have been made to develop a method for bracing the quadriceps-deficient subject. Several purely mechanical systems such as ratchet devices (2,3), cog and dog assemblies (4), polycentric hinges (5), and tang in clevis(6), have all been proposed. These designs rely upon ankle joint motion, brace piston action, or hand operated elements to control knee flexion. Other attempts have applied electronic controls and actuators to hydraulic cylinders (7), spring clutches (8), and multiple leaf disk brakes (9). Various transduceable events such as ankle flexion/extension angle, shank inclination, brace element strain, and foot-floor contact have been used for brace control input (7,8).

STATEMENT OF PROBLEM

There have been many proposed solutions to the need for an orthotic knee joint that would allow knee flexion during swing phase and flexion restraint during the stance phase of gait. However the efficacy of these designs have not been proven. No scientific tests have been conducted on individuals that require long leg braces for ambulation which document any objective measure of efficacy.

RATIONALE

The goals of this project were to design, build, and test a long leg brace system that would 1) provide complete stability in stance phase and unrestricted knee movements in swing phase , 2) be self-contained, and most importantly, 3) reduce the energy consumption required for ambulation.

DESIGN

The brace control components included a mechanical clutch to control the knee joint, electronic control and power circuitry, and footswitches, which provided control input for the electronics. A wrap spring clutch was selected for this application because it is self-engaging, requires minimal disengagement force, and engages silently at any angle. Two clutch designs (28 and 56 Nm) were produced based upon optimizations carried out to minimize clutch size. The Broyden, Fletcher, Goldfarb, and Shanno Quasi-Newton method was used to optimize the various clutch parameters which include clutch diameter, length, torque capacity, and disengagement force.

Clutch regulation was based upon the finite state theory with control input obtained from bilateral footswitches. A compact electronic controller receives input from foot floor contact sensors (Interlink, Santa Barbara, CA) located under the heel and forefoot of each foot. The sixteen possible combinations of these four footswitch inputs are stored in an Electronically Programmable Read Only Memory (EPROM) (SIGNETICS 27C64A), along with the appropriate output responses. The EPROM output is used to control electronic drive circuitry for output is used to control electronic drive circuitry for a linear solenoid (Guardian Electric, Chicago, IL) which is connected to the wrap spring clutch control collar. The control circuitry and battery power supply are held in a waist pack worn by the user. This embodiment of the electronics system occupied 819 cubic centimeters and weighed 5.5 newtons (including the battery pack).

DEVELOPMENT

A single standard Knee-Ankle-Foot Orthosis (KAFO) was made for each subject tested. Fabrication and fitting of each KAFO were performed by a professional orthotist. To incorporate the components of the new control system, the lateral hinge of each KAFO were removed and replaced with a wrap spring clutch. Special care was taken to maintain knee joint alignment as determined by the orthotist.

EVALUATION

Kinematic data were collected using a five camera computerized photogrammetry system (VICON, Oxford Metrics, UK). Analysis was performed using proprietary software written for clinical motion studies.

Cardiovascular energy assessment was carried out while each subject walked on an electronically controlled treadmill. Subjects breathed through a suspended mouthpiece which allowed vertical, lateral, and forward/backward movement with changes in head position. A mass spectrometer and a volume turbine were attached to the mouthpiece. The output of these transducers were interfaced with commercially available software to calculate and average many variables on a breath-by-breath basis. Data were collected at when a steady state condition were reached. Walking velocities ranging from 1 to 3.2 km/hr and treadmill grades of 0 and 5 %grade were used.

Three subjects were tested using this brace system. Subject number 1 was a 30 year old male having no significant physical handicap. Subject number 2 was a 70 year old male, with unilateral paralysis due to polio. Subject number 3 was a 40 year old male with unilateral paralysis due to polio. Each subject was tested under two brace conditions: 1) Brace locked, simulating a standard KAFO with the knee joint locked, and 2) Brace system activated.

RESULTS

Motion Analysis

Dynamic gait measurements made on subject No. 1 showed that the activated brace allowed nearly normal knee flexion during swing, while providing flexion restraint during stance (figure 1). In contrast, the locked brace eliminated knee flexion during swing .

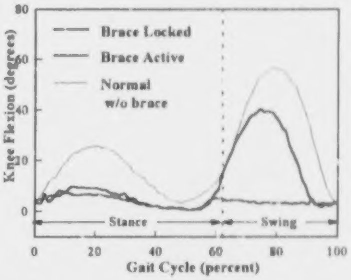

Figure 1. Knee Flexion Subject #1

Motion analysis of subject No. 2 showed that the active brace allowed more normal hip motions, as well as a knee flexion/extension dynamic range of 20 degrees. A 19% increase in cadence and a 27% increase in walking velocity occured when the brace system was activated.

Motion analysis of subject No. 3 showed that the active brace allowed more normal motions about the hip, along with a dynamic range of knee flexion/extension of 35 degrees. Walking velocity increased by 13% while cadence increased by 3%. The velocity increase was due primarily to an 11% increase in step length.

Physiological Energy Expenditure

Physiological energy measurements obtained from subject No. 1 show that the oxygen consumption rate (normalized by body weight) for the brace active condition is from 3 - 12 % less than that for the locked condition. All data were collected at 0% grade.

Subject No. 2 was too weak to maintain an erect posture while walking on the treadmill for energy measurements with the brace locked. However, this subject was able to ambulate on the treadmill with the brace activated.

Subject No. 3 was able to complete the physiological energy measurement protocol. At 0% grade the oxygen consumption was lower for the active brace condition for all speeds over 1 km/hr. Measurements at 5% grade show the active brace condition consistently required less oxygen for walking speeds of 0.96, 1.6, and 2.4 km/hr (figure 2).

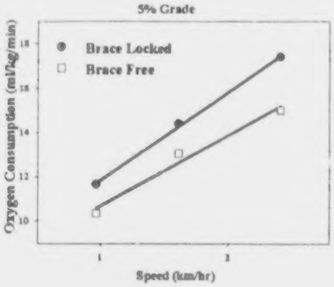

Figure 2. Oxygen Consumption Rate Subject #3.

DISCUSSION

Practicing clinicians and orthotists have few options available to them when treating weak or paralyzed knee extensors. Functional knee orthosis designs abound. However few applications have been tested in a clinical setting. The need for a knee brace which allows appropriate flexion and extension is supported by cardiopulmonary studies showing an oxygen cost (ml/kg/m) increase of 23 - 33% when the knee is immobilized in healthy subjects(10,11).

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VALUING ASSISTIVE TECHNOLOGY INVENTIONS

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Abstract

We developed a simple method of valuing the Net Present Worth of an invention based on formulae used by the finance and insurance industries. Most inventors have inflated views of their invention's worth, making negotiations difficult. This model has been used in negotiations of license agreements and has proven to be useful. It provides a model into which negotiators can frame their questions and demands, and in which they can assess the "reasonableness" of the demand. It is particularly useful when negotiating payments in advance of royalties, because it demonstrates the impact the advance will have on the royalty rate, and how that can impact the future returns.

Background

The RERC on Technology Evaluation and Transfer works in collaboration with AZtech Incorporated, a not for profit company run by and for persons with disabilities. AZtech solicits assistive technology devices from inventors and evaluates them. For devices that address a significant unmet need in the marketplace, we seek to license the device to a manufacturer who will bring it to market. (1) For the majority of inventors, the wisest strategy is to try to license their invention to an existing enterprise. Until there were programs like AZtech , "the resources available to independent inventors were limited; the majority of professional technology transfer agents are employed by or represent ongoing enterprises." (2)

Often the inventor has an inflated view of the value of the device. "Defining value requires looking at the technology from adopter and end customer points of view." (3) The differences in perceived value of the invention by the inventor and the manufacturer must be resolved before a licensing agreement can be negotiated.

Objective

This paper outlines a method of assessing the value of an invention. The figure arrived at is used as a starting point in the negotiation with inventions and companies. We agree with Dr. Lindquist in that "we attract [companies] to the negotiating table by communicating the value of what we offer. That is, we attract [companies] through contact with ideas or inventions that are focused on value." (4) The value or figure can also be used to demonstrate the impact advance payments and minimums can have on royalties. The negotiators then have a model in which to frame their expectations and questions.

Method/Approach

The value of a license is influenced by a number of factors including market size, growth rates, existing competition, and substitute products. Compound interest formulas used in the banking and insurance industries can be applied to arrive at an estimated value based on future cash flows. By making a few assumptions, such as a sales forecast for the life of the contract, the formula becomes simple enough for anyone to use. In the formula below, P is the Net Present Value of the license, the figure we seek. R is the periodic deposit, or the Royalty Stream. For simplicity, we have assumed constant sales for each year of the contract, resulting in a steady royalty stream for the duration of the agreement. A fairly simple program could be written to emulate a much more complex royalty stream, with increasing sales. The symbol i represents the nominal interest rate, n represents the number of years of the contract, and m represents the number of times the royalty will be paid during the year. The formula is:

$P = R * [(1+i/m)^{mn} - 1]/[(i/m)*(1+i/m)^{mn}]$
The royalty is typically based on a percent of the unit selling cost. The royalty stream, R, is calculated by making an assumption of what the royalty rate will be, how many units will be sold each year, and the revenue to be realized each year on the product.

Results
For example, let us assume we have a wheelchair accessory. We have done preliminary market analysis and forecast sales to reach 7,050 units in year one, (588 units per month), and hold constant at that level for the life of the contract. We have also conducted consumer focus groups and have concluded that this volume can be achieved if the accessory is sold by the manufacturer for $60.00 each. If the royalty rate is three percent, the royalty stream R would be:

588 units per month * $60.00 per unit * 0.03 = $1,058.40 per month

If the royalty rate is increased to five percent, the monthly royalty stream increases to $1764.00 per month.

"Royalty percentages vary from 1% to 20% (or even more), but 1-3% of net sales is realistic for the rehabilitation field. The percentage may be even less if the invention is a component of a product." (5)

To calculate the Net Present Value, values for R, m, n, and i need to be plugged into the formula. If we assume a value of i of five percent, which is roughly equivalent to what a safe investment such as a bank deposit will yield, with a seventeen year agreement, P can be calculated as follows:

$$P = R * [(1+.05/12)^{204} - 1]/[(.05/12)*(1+.05/12)^{204}]$$

$$P = R * (2.3355 - 1)/(.004167 * 2.3355)$$

$$P = R * 137.24$$

For R equal to $1058.40 per month, (3 percent royalty) P = $145,200

For R equal to $1764.00 per month, (5 percent royalty) P = $242,091

An inventor may want an advance payment or fee in return for offering an exclusive license to a company. When this figure is negotiated it is based on the value that the company places on the license and is independent of the inventor's investment of time or money. In the above example we negotiated an advance payment of, say, ten thousand dollars, then the new net present value, P', is P minus the advance payment. With a three percent royalty rate, we find:

P' = P - $10,000
P' = $135,200 = R * 137.24
R = $985.14

R = Royalty Rate * Monthly Units * $/Unit
Royalty Rate = 985.14 / (588 units/mo. * $60/unit)
Royalty Rate = 2.8 percent

With this calculation, we can demonstrate to an inventor the impact an advance against royalties will have. The royalty rate will be lowered, not only for the forecasted volume, but for any volume over the forecasted amount. Depending on the amount of risk the inventor is willing to take, and their confidence in their invention, the minimum acceptable advance may change.

Discussion
This type of analysis is used with inventors who submit their devices. It has proven to be helpful in getting them to understand how to value their invention. The calculations are not difficult to set up on a spreadsheet such as Lotus® or Excel®. By understanding the underlying math, they can be made quite sophisticated, but this is not typically necessary at the early stages of the negotiation.

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CUSTOMER ORIENTATION: KEY TO DELIVERING USEFUL ASSISTIVE DEVICES

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ABSTRACT

We present the RERC-TET's protocols for a customer-oriented approach to designing and marketing new assistive devices. Our methodology places the customers at the apex of product related decisions. The technical and marketing teams work to interpret the customers' requirements, and find the most cost efficient solutions to their needs. We describe our results with these protocols.

INTRODUCTION

People with functional limitations may benefit from using assistive devices. Unfortunately, the experience of the users of such equipment has not been satisfactory.[1,2] Batavia and Hammer describe it as a pattern of "adoption and abandonment."[3] The person with a disability receives an assistive device through a clinical selection process. Once in use, the individual discovers that the device fails to meet his/her needs. Frustrated, the individual abandons the device and chooses another to fill the gap. Unfortunately, this cycle may repeat several times before an adequate solution is found (if ever).

These cycles present multiple problems for sellers, buyers and users. The consumer's quality of life is not optimized. Second, third-party payers lose revenue through the consumer's abandonment cycles, and pass those losses on through higher premiums, higher taxes and more restrictive approval policies. Finally, manufacturers of assistive devices lose business or constrain their growth by manufacturing devices which do not fully meet customer needs. As a result, they lack the economies of scale needed to operate at a reasonable profit margin, nor are they able to offer lower prices to consumers.

These marketplace problems and their associated economic waste can be minimized by adopting a customer orientation to the marketing of assistive devices. Towards this end, the RERC on Technology Evaluation and Transfer, developed protocols for a methodology to improve the quality of new assistive devices introduced to the market. These protocols help us screen, select, develop and offer for commercialization, inventions submitted to the program. Invention evaluation is supported by funding from the National Institute on Disability and Rehabilitation Research .

METHODOLOGY

Our customer-oriented approach to the marketing of assistive devices requires that the entire focus of the marketing effort be to solve customers' problems. We work with the inventors and manufacturers to identify their customers, choose from among them those they wish to serve, find their needs, establish technical specifications in order to meet customer requirements within the price constraints imposed by the customers, differentiate their offerings from those of the competition and communicate these differences to the market place. In the following we briefly elaborate on each phase of this customer oriented philosophy.

Define Customers - Our program is based on the belief that active participation of the customers in the product design process is key to delivering useful new products. We define the customer as the "end user" (person with a disability), "secondary users" (family members or care providers), and the "prescribers" (if professional selection is required). Depending on the product, all three groups may be viewed as the customer. The end user must ultimately bear the consequences of a poorly designed assistive device and hence must be heard to ensure that the product will be used. The family member or care provider, where appropriate, may have functional requirements which, unless met, may make the assistive device useless. The "professional" provides input based upon his/her understanding of how the device addresses the functional impairments or medical necessity needed to justify purchase or reimbursement.

Customer Requirements - We involve customers in our process to clearly establish the requirements which must be met if the device is to gain acceptance in the market place. We accomplish this by conducting focus group interviews in which the three customer groups: "end users", "secondary users" and "prescribers" actively participate. We identify and select focus group participants based on function -- that is the function provided by the device as compared to the functional limitations of the participants. By focusing on function, we avoid the mismatches possible by disability type, primary versus secondary disability, medical diagnosis, age group or gender bias.

The customers discuss the specific function under consideration, describe the benefits sought from an assistive device for that function, and define and prioritize their criteria assessing these benefits. The customers then describe the extent to which the various devices currently available in the market do or don't meet their requirements. This enables us to identify the critical deficiencies in the assistive devices being sold in the market. By developing a device that addresses these deficiencies, we work to ensure customer satisfaction and eventual success in the market place.

Batavia and Hammer identified seventeen general functional criteria (e.g., durability, reliability, repairability, etc.) for evaluating assistive devices. Our work has since refined those seventeen into eleven criteria.[4] We now know that the definitions of these criteria change, depending on the specific type of assistive device being evaluated. The manufacturer's task is to deliver on these consumer criteria, so we must verify with customers that these criteria have been met. We are developing the information necessary to tell the manufacturers what "portability, reliability and durability" mean to wheelchair users versus voice-output users, so they can incorporate design features that ensure customer satisfaction on those criteria.

Next, an alpha version of the proposed assistive device is demonstrated to the participants in the focus group and they are asked to evaluate it on the criterion previously established by the group. This helps us to determine extent to which the alpha version could meet customer requirements. Suggestions are sought from the focus group participants to make the device better suited for meeting their requirements, typically resulting in a consumer-driven description of a beta version.

Customer Based Price - The success of an assistive device in attracting a significant proportion of the target market will ultimately depend upon the price. Affordability remains a key criteria for the customer base. A typical approach for estimating price is to add up the cost of components and apply a mark-up to cover administrative cost and profit margin. A factor is applied to this "ex-factory" cost to cover for wholesaler and retailer markups in order to determine the price to be charged from the end user. However, this method excludes the customers from the pricing decisions. We believe that the product's worth to the customer -- the amount which they are willing to pay for the benefits provided by the assistive device -- should be the guidepost for any pricing strategy.

In a customer based pricing strategy, focus group participants state the price they would be willing to pay for the prototype, assuming the suggested changes have been incorporated in the device. We then deduct the desired profit margin and other overheads associated with sales and distribution, to arrive at the "target cost" a manufacturer must achieve to make the product attractive.

Design Considerations - The RERC-TET's consumer team passes the results of the focus group over to the technical and marketing teams. The technical team then establishes design specifications for the prototype which would meet the expressed customer requirements.[5] During the design process, priority is given to attributes considered to be of greatest importance by the consumers and where substantial gap exists between the consumer requirements and the current market offerings. The marketing team uses the consumer imposed cost constraints developed during the previous phase, to drive the search for competing technologies, methods for manufacturing the device, and distribution channels. The prototype device is then offered to manufacturers for commercialization through license or purchase.[6]

Differentiation and Communication - If the device is not commercialized because it lacks needed refinements, or we are unable to communicate the device's potential successfully, the RERC-TET may elect to partner with the inventor and generate the beta second iteration. It is not enough to design just another product. For an assistive device to gain a differential advantage, the differences in the market offering have to be meaningful -- they must address critical unfulfilled requirements of the target customers. We are focusing on the customer-identified gaps in the current market offerings and assigning greater importance to these product requirements during the design phase. This will be particularly critical when a manufacturer or our internal product design teams must make crucial trade-offs between the device features and performance levels to live within the customer-imposed cost restraints.

An otherwise perfect assistive device could fail in the market place if the customers do not know about its existence and ability to solve their problem. They must be able to quickly grasp what differentiates the manufacturers offering from the crowd and why buying it is in their best interest. For customer awareness, the RERC-TET depends heavily on active companies in the marketplace, on professional societies such as RESNA and on NIDRR-funded projects like the State Tech Act programs. We expect our knowledge of the target customers, their expectations from particular assistive device, perceptions of the competing alternatives and the proposed offerings, will be useful information to disseminate through our partners in the assistive technology marketplace.

OUR EXPERIENCE

Over the past two years, we applied these protocols to about thirty assistive devices -- out of over 140 submissions. More than 500 consumers, family members and professionals have participated. While most assistive devices were rejected by focus groups for lacking meaningful benefits to users, a select few benefitted from the consumer orientation. About ten devices are being licensed to companies for manufacturing and sale.

Consumers have strongly endorsed this process. In follow-up surveys 91% of the participants (35% response rate), think customer evaluation of new assistive technology is needed to ensure the introduction of "right" products in the market. Most (87%) thought their participation in the focus groups was either "extremely" or "very" productive.

Inventors also endorsed this process. Our survey revealed that 88% would recommend our program to other inventors (40% response rate), despite the fact that most received evaluations that discouraged continued development of their inventions. The consumer-directed information we share in the device evaluation, provides them with a better sense of the unmet needs of their perceived customers.

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CONSUMER CRITERIA FOR ASSISTIVE DEVICES: OPERATIONALIZING GENERIC CRITERIA FOR SPECIFIC ABLEDATA CATEGORIES

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ABSTRACT

Prior research generated a set of generic consumer evaluation criteria. Device dissatisfaction and abandonment remains high, so the generic criteria are either not applied or require further refinement. The RERC-TET developed more detailed consumer criteria for a dozen ABLEDATA categories where consumer dissatisfaction is reported to be quite high. Results are included in a publication available from the authors.

BACKGROUND

Consumers lament the lack of user input to the design and development of many assistive devices. Their argument is that increased consumer input will improve the quality of such devices. In response, studies have elicited consumer opinions about assistive devices [1,2,3]. A landmark study established a set of seventeen generic criteria, ranked in order of the perceived importance to consumers [4]. In that article, about a dozen people with various impairments rank-ordered the categories, and the article reported the sum of mean ranks across all participants.

The RERC-TET, funded by NIDRR, is working to improve the quality of assistive devices available in the marketplace. Improving devices includes new devices to meet previously unmet needs, or modified devices to better meet consumer needs poorly met by existing devices. The RERC-TET is working from the supply side (technology push), by evaluating prototype inventions and helping to commercialize those inventions offering value to the consumer. The RERC-TET is also working from the demand side (technology pull), by involving the customers (consumers, family members and professional care providers) in the evaluation process.

The results from about fifty-five focus groups on ten devices -- about seven hundred participants -- indicated that the Batavia and Hammer consumer criteria [4] need further refinement. When a focus group applies those seventeen criteria to a specific device, their definitions and relative rankings change. Our experience indicates that the definitions and rankings will vary across device categories, if not for every device. Further, most consumers preferred to collapse several categories under one heading. We developed a subset of the original seventeen criteria, by combining criteria that consumers identified as redundant. Our working subset contains eleven criteria (one quantitative -- affordability, and ten qualitative). The revised set of eleven criteria collapsed the original seventeen by Batavia and Hammer as follows:

AZtech/RERC-TET Criteria	**Batavia / Hammer Criteria**
1. Effectiveness	*1. Effectiveness*
2. Affordability	*2. Affordability*
3. Reliability	*3. Dependability*
4. Portability	*4. Portability*
5. Durability	*5. Durability*
6. Securability	*6. Securability*
7. Physical Security/Safety	*7. Physical Security*
8. Learnability	*8. Learnability & 9. Ease of Assembly*
9. Physical Comfort/Acceptance	*10. Personal Acceptance &* *11. Physical Comfort*
10. Ease of Maintenance/ Repairability	*12. Ease of Maintenance,* *13. Supplier Maintainability* *14. Consumer Repairability*
11. Operability	*15. Operability,* *16. Compatibility &* *17. Flexibility*

The RERC-TET took advantage of the opportunity to refine these criteria. To provide consumer evaluations in a timely manner, the RERC-TET had already established a network of fourteen consumer agencies around the nation. Every site has demonstrated its capacity to conduct consumer evaluations across disabilities and across age ranges. The site's distribution reflects geographic, demographic and ethnic diversity. To assist researchers, manufacturers and consumers, the RERC-TET had these sites hold focus groups, to establish more specific consumer criteria for selected device categories.

METHODS

How were the selected categories chosen? The RERC-TET's consumer team surveyed the fifty-five State Tech Act programs (n = 32; 58% response), 320 Independent Living Centers (n = 41; 13% response) and consumer participants from both the National Independent Living Council Annual Conference, and the New York State Coalition on Independent Living's Annual Meeting (n = 67). In all cases, the survey team worked to identify the organization's point of contact for assistive technology issues.

The survey instrument listed the seventeen general ABLEDATA categories. It asked respondents to select the five ABLEDATA categories most in need of additional product development, or most in need of improvements to existing products. It then asked the respondent to provide specific examples of the devices requiring substantial improvement within that ABLEDATA category. Response totals indicated the rank order of device categories, with those categories selected more frequently representing more need of development or improvement. The following list shows the ABLEDATA categories identified most frequently (actual category in boldface and preceding branches in italics). These are the device categories most in need of new product development or existing product improvement.

ABLEDATA Product Categories in Greatest Need of New or Improved Products

- *Architectural / Indoor /* **Bathrooms**

- *Wheeled Mobility /* **Wheelchair Accessories**
- *Architectural / Indoor /* **Doors**
- *Architectural / Indoor / Doors /Door Operator/Windows /* **Window Opening Aid**
- *Architectural / Vertical Lift /* **Ramps**
- *Communications / Signal Systems / Special Dialing Telephones /* **Voice-activated Telephone**
- *Transportation / Vehicle Accessories/ Van Accessories/* **Van Lifts and Ramps**
- *Computers / Hardware / Input /* **Voice Input Interfaces**
- *Transportation / Vehicle Accessories / Van Accessories General /* **Wheelchair Restraint System**
- *Seating /* **Cushions**
- *Computers / Hardware / Input /* **Voice Output**
- *Sensory Disability / Blind and Low Vision / Reading/Reading General /* **Voice Output Reading Machine**
- *Vocational Management / Work Stations/* **Specialized Work Stations**
- *Wheeled Mobility / Wheels /* **Quick Release Wheel Axle**

FOCUS GROUP PROCESS

The RERC-TET's Consumer team then organized and conducted industry standard consumer focus groups, for the top device categories identified through the survey. These focus groups were held in the fourteen evaluation sites across the country. Each device received four focus groups held in various sites. Each focus group had 8 to 15 potential customers of the assistive device (average of 13 per group), with an average number of 52 participants per device (Industry norm n = 50). The focus group process roughly mirrors the RERC-TET's internal evaluation process for evaluating prototype assistive devices. The focus groups participated in the following five steps:

Step 1 - Initial Consumer Criteria. We introduce consumers to the concept of evaluation criteria by asking them, "When you are about to purchase an assistive device, what criteria do you consider?" We record all responses for each group, then collapse responses across groups. We keep the full list of discreet answers. After each we note which of the four groups gave the response and thereby have a count across all groups. For example, "ease of learning to operate (1,3)" means this criteria surfaced in two groups, group one and group three.

Step 2 - Consumer Criteria for Ideal Device. We introduce the specific device category of interest, then we move through the eleven criteria. We present the eleven criteria in different orders for each group. We say, "We are going to discuss [device category] devices. With the ideal product in mind, how would you judge [each of eleven criteria]? For example, for the criterion "reliability," we ask, "How would you judge whether a device provides repeatable, predictable performance, and levels of accuracy under reasonable use?" As in Step 1, we record all responses in each group, then collapse the responses across groups. We repeat the process for all ten consumer criteria.

Step 3 - Ranking Consumer Criteria. Having established the consumer's familiarity with all eleven categories, we ask each group to rank order the eleven categories using a modified Delphi process. In this process, each category is compared to all other categories one at a time, until the relative importance is established between all eleven categories. The rank orders are averaged across the four focus groups to derive a final rank order.

Step 4. Consumer Satisfaction with Existing Devices. We next determine how existing products known to our participants rate across the eleven criteria. We say, "Earlier we identified some examples of [assistive device] on the market. Keeping those in mind, how well do those examples satisfy the consumer criteria?" The answers are essentially a report card on the current array of devices in the marketplace. Again, all discreet comments are recorded with multiple comments noted by number and group.

Step 5. Suggestions for Improving Existing Products. The final step is an open-ended opportunity to suggest any and all improvements needed by the device category under review. We say, "Earlier you identified some examples of ideal [device]. At this time, let's list all the ideas and suggestions that come to mind for making [device] more accessible. Regardless of how impractical they may seem or how expensive they may be." These responses are arranged according to frequency across groups.

RESULTS

The RERC-TET is compiling the results of this work in a publication available from the authors.

ACKNOWLEDGMENT

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ADAPTING AND DESIGNING PRODUCTS FOR PERSONS WITH DISABILITIES

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ABSTRACT

Ice Skating has been largely inaccessible to persons with severe disabilities. Through our experience in SABAH, The Skating Association for the Blind and Handicapped, Inc., a series of devices have been designed to make skating more accessible. With our planned national expansion over the next five years, more persons with all levels of disabilities will be able to ice successfully.

BACKGROUND

The Skating Association for the Blind and Handicapped, Inc. (SABAH), is entering its 20th year of teaching persons with physical and mental disabilities to ice skate. Starting at 16 months of age through adulthood over 8,000 persons have learned to skate successfully. Trained volunteers work one on one or two on one with the skaters to develop skills, and skaters progress to more challenging skill levels. All skaters participate and perform in annual ice show spectacular that over 12,000 spectators attend. Currently 4000 people around the country desire a SABAH program in their communities.

STATEMENT OF THE PROBLEM

As the program has grown persons with increasing severity of physical disabilities have desired to be included. Spina Bifida, Spastic Cerebral Palsy and a variety of conditions in which the student is not able to bear weight have necessitated new equipment. Special foot and orthotic needs have necessitated new skate designsThree types of walkers, three types of ice skates, and two types of harnesses have been recently developed to address these needs.

RATIONALE

In the matter of the ice skates there was nothing on the market that fit a skater wearing an AFO, or other orthotic. There also was nothing appropriate for persons with Down Syndrome or a Clubbed Feet . The walkers that were available went out of business and there was nothing available for the partial or non-weight-bearing skater. The harnesses that were available did not work well in this setting and were very expensive.

DESIGN

Walkers:
To adapt walkers a skater's father welded pipes in his basement and brought a few basic designs to the rink. As the skaters used the new walkers, we changed the width, height of the support bar and overall dimensions to accommodate the leg and gait swing necessary for skating movement. A similar process was used for the non-weight-bearing skater additionally incorporating a sling seat in the center of the walker. A third height was added to the basic model walker.

Skates:
Based on my experience as a professional skater and as a teacher of over 8,000 persons with disabilities, I contacted Riedell, a major skate manufacturer and expressed my frustration in trying to fit AFO's into skates and the problem with fitting persons with Down Syndrome and Clubbed Feet. They suggested that I design something and they would work with us as the manufacturer.

Harness:
I asked our costume designer to create what

was needed for torso support including where the handles needed to be for the volunteers.

DEVELOPMENT

A trial and error period followed the design phase where multiple users were put in the walkers and the design was continually modified and improved. The feet of children and adults with Down Syndrome and Clubbed Feet were photographed and measured. AFO's were collected and studied in a similar matter. At the skate factory I picked out materials to include in the new skate design. Working with their custom skate specialist, I communicated the design changes necessary. For model #1, for persons with Down Syndrome or Clubbed Feet fourteen changes were necessary from their basic skate design. For model #2 for persons wearing AFO's all of the first fourteen changes and an additional 10 were necessary. A few models of each type were made and put on the ice. Over time additional changes became apparent. The harnesses were tested in the same manner and materials occasionally changed.

EVALUATION

Last month the RERC on Technology Evaluational Transfer convened experts in the orthotic and gait fields in Buffalo to examine the designs and see the skates in use. The RERC-TET is evaluating these products for potential commercialization. The unanimous feedback was very positive. All these specialists were excited that such products had been designed and tested with users and they were excited about the future availability of the skates for their clients.

DISCUSSION

The skates and other products are helping persons with disabilities skate.
The SABAH program is successful in Western New York and with nineteen years experience and over 8,000 SABAH skaters is planning a national expansion over the next five years. SABAH's expansion will provide larger markets for these products.

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None

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The author would like to acknowledge the Riedell Shoes, Inc., company for their support in the skate development and Franbilt, Inc., for their work on the walker designs and Susan Drabik for her help with the harnesses. Thanks also to the National Institute on Disability and Rehabilitation Research, U.S. Department of Education for funding the RERC-TET.

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DESIGN ACTIVITY IN THE CONSUMER INNOVATION LABORATORY

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ABSTRACT

The Consumer Innovation Laboratory has been actively engaging consumers in the product design process. This paper presents an overview of the consumer and staff project activity levels, as well as information about the types of activities and the design progress. Although no formal conclusions may be drawn at this stage, the data presented here may eventual form the basis for more efficient guidelines for consumer involvement in product design.

BACKGROUND

This paper presents information about the design activities of the Consumer Innovation Laboratory, and the role of the participants in those activities. The Consumer Innovation Laboratory is a consumer-led and consumer-driven research effort designed to explore new methods of integrating consumer knowledge and expertise into a "total design process"[1]. The project, which began in 1993, is one of thirteen projects within the Rehabilitation Engineering Research Center (RERC) on Rehabilitation Robotics of the University of Delaware's Center for Applied Science and Engineering, located at the Alfred I. duPont Institute.

The concept behind the Consumer Innovation Laboratory is to engage consumers to work as peers with staff engineers in the development of product solutions to everyday needs. In their team roles with the engineers, the consumers share in the responsibility for taking project ideas from their inception, through the development of working models, to their submission to manufacturers for commercialization.

DESIGN TEAMS

The Consumer Innovation Laboratory currently supports three active design teams. Following is a short description of the objectives of each.

Eggbreaker: The goal of this team is to create a product that will break an egg and cleanly remove the contents for people with limitations in hand function.

Vacuum cleaner: The goal of this design team is to produce a more accessible method for vacuum cleaning, especially for people who use wheelchairs.

Pageturner: The goal of this design team is to create a next-generation pageturning device.

DESIGN ACTIVITIES

The Consumer Innovation Laboratory uses a total design process. All designs begin with a blank sheet of paper and progress through a series of stages. A short description of the activities of which follows.

Product Design Specification (PDS): This stage involves discussing the desired criteria for the end product. These criteria are independent of any form of the final product. In addition, the criteria are rated as either vital to the product or useful if possible. The top five or ten vital criteria are also identified.

Patent and Product Review: In order to determine whether the consumer need may already have been met, a review of pertinent patents and existing products takes place.

Market Evaluation: In this stage, effort is put into identifying more broadly what criteria potential consumers have for the product. The primary mechanism for this has been questionnaires.

Testing and Prototyping: The testing and prototyping stage begins with a series of brainstorming sessions. These sessions serve as the transition from PDS to form and function. Testing of some of the brainstorming ideas takes place and a prototype is developed based on the most promising solutions identified.

Technology Transfer: This stage involves identifying and discussing with potential manufacturers of the product.

DESIGN STATUS

The status of each design team is described in Figure 1. For each design team, the level of activity (in total hours per project month) per team member is shown. In addition, a bar graph along the top indicates the design activity that took place during those months. These graphs, therefore, indicate the length of time a project has been running, the various design activities accomplished, and the relative contribution of the various team members during those activities.

The eggbreaker project has been active for 21 months. As shown, the activity of this project has oscillated somewhat, which is reflected in the team's progress.

The data displayed for the vacuum cleaner project shows that in the beginning of the PDS stage, the

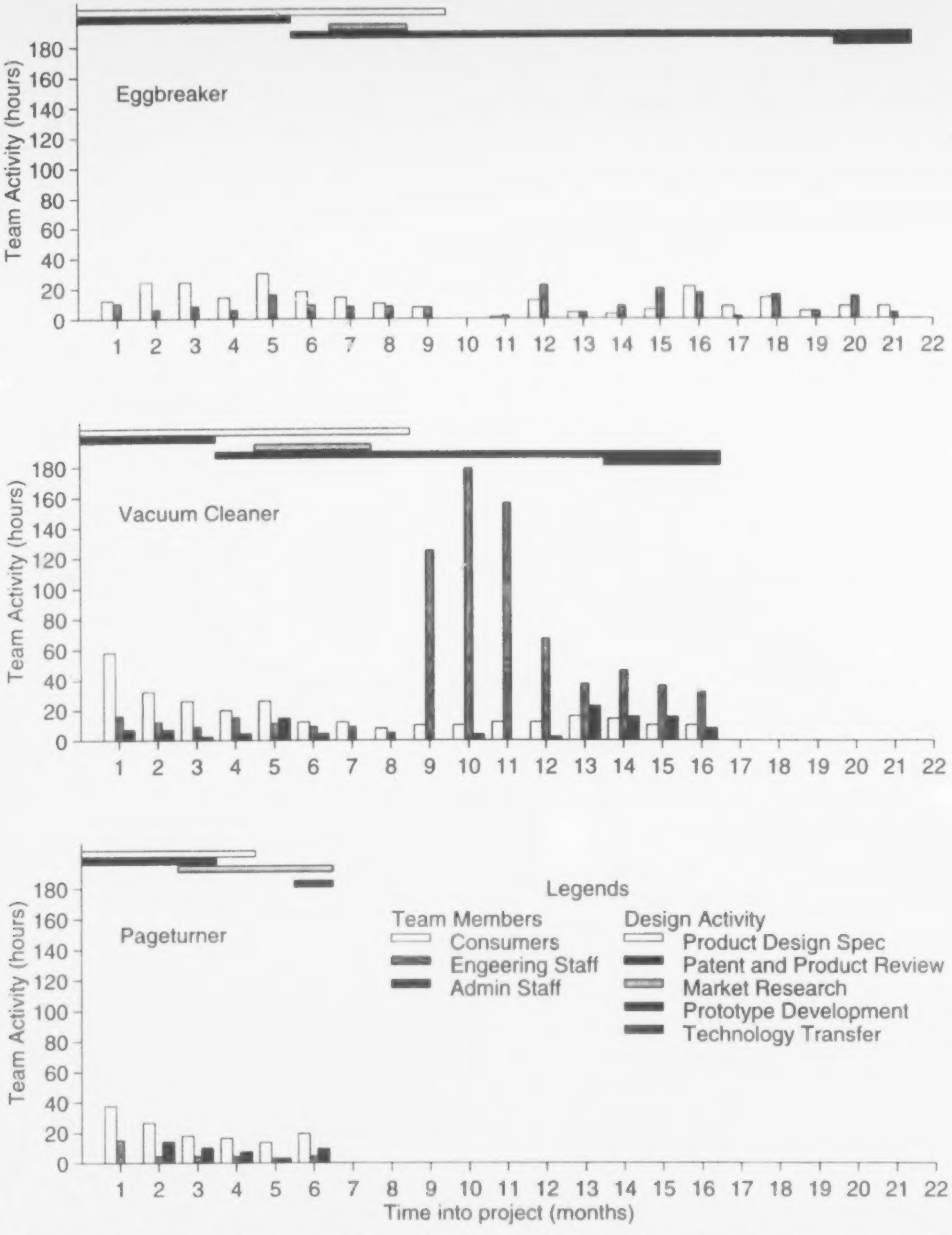

Figure 1. Design activity charts for the three design projects. The x-axis represents the time into a design project (in months) and the y-axis indicates the total hours contributed to that activity during the month. The activity levels are broken down into consumers, engineering staff, and admin support. The bar graphs along the top indicate the periods during which a particular design activity was taking place.

consumer input was relatively high. This input, however, gradually reduced and leveled off. During the specification and construction of the prototype, the engineering staff input was quite high. It is interesting to note that the consumer activity rises slightly after the engineering activity. This indicates the time spent by consumers evaluating the prototype.

Although it is still early in the project, the pageturner design activity appears to be following that of the vacuum cleaner project. Another observation is that the amount of time required to create the PDS appears to be dropping with each new design team. This may be a reflection of the experience being gained with each successive design in more efficiently moving through this process.

Figure 2 shows the total number of hours spent by the design team members on each project. In total, 663 consumer hours, 988 hours by engineering staff, and 152 hours for administrative support has been spent on the detailed design activities of the three design projects combined.

CONCLUSIONS

It is hoped that by examining the activity levels of the design team members, an efficient methodology for consumer-initiated design will develop. The data shown in Figure 1 suggests that different design activities require different input.

A missing element that will enable this to be more meaningful is a measurement of the effect of the design activity on the quality of the design. Attempts will be made to identify such a parameter as the designs continue to be monitored.

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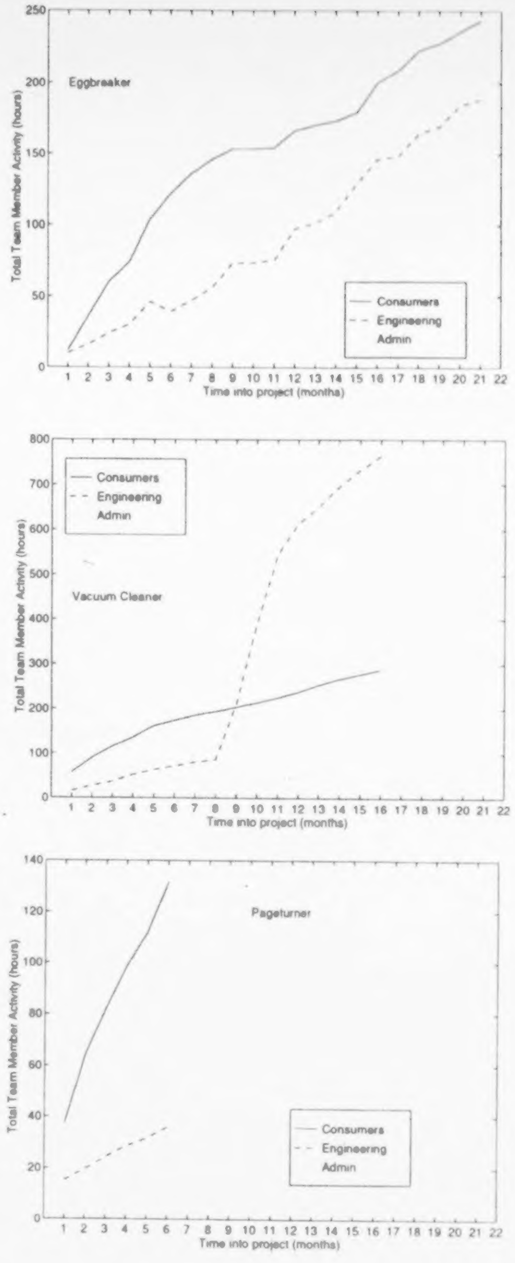

Figure 2. Total hours contributed to design activities.

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TECHNOLOGY TRANSFER: THE VIRTUAL PRODUCT MODEL

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ABSTRACT

We present a methodology for the transformation of a device concept into a market product guided by prioritized customer requirements, market and technical constraints. Our methodology seeks to best meet the customer's needs while maximizing a device's market . The methodology is well suited for use within a small company framework.

INTRODUCTION

The RERC on Technology Evaluation and Transfer is supported by the NIDRR to transform inventions into useful new assistive products. The transformation process is a collaborative effort between consumer, marketing and technical teams.[1] The consumer team defines the function and performance characteristics necessary to optimize a device's value.[2] These characteristics are developed by examining existing products, and by comparing the prototype device to consumer expectations. These characteristics, organized under eleven consumer criteria, represent the consumer's version of the ideal device.[3]

The RERC-TET offers promising inventions for license or sale to manufacturers. However, at this early stage of evaluation, no ideal device actually exists and it is premature to develop one. We have the prototype invention, any relevant products, and the consumer's additional criteria. We needed to know if any company is interested in the device before investing additional resources. In response, the technical team developed the "Virtual Product Model." This is a method for translating the consumer criteria into device attributes, and presenting those attributes in a matrix. The matrix compares the features of the ideal device and of all existing products, to the set of consumer criteria. The Virtual Product Model provides companies with a snapshot of the prototypes potential value, in relation to both user expectations and less optimal products.

BACKGROUND

Quality Function Deployment

Quality Function Deployment (QFD) is a planning tool that was developed by the Mitsubishi Heavy Industry in Japan to translate customer needs and expectations into design specifications. QFD results in shorter product development time, and reduction of problems during actual production. Although QFD offers several benefits, it is more suitable to large and medium-sized companies than to small companies. A survey was carried out by [4], and the results indicate that QFD helps break down department and organizational barriers in large companies. Some important issues such as how new technology is incorporated in the effort, dynamics of product team selection, and integrating functions such as purchasing into the QFD model are yet to be addressed.

The Small Company Model

The development of new products requires technical and market expertise, knowledge of customer requirements, infrastructure, capital, and established methodology, including timelines, and a statement of problem definition, and deliverables. Medium to large companies are generally rich in technical and market expertise, have good plant infrastructure and are well capitalized. In the event that a new product is not successful in the market, these companies are often not much affected by the financial setback.

In contrast, small companies often operate on tight budgets and are under constant pressure to "be right the first time" when they design and develop a new product. They are usually deficient in technical and market expertise, lack plant infrastructure and are under-capitalized. The time from concept to market has to be minimized due to the fact that larger competitors generally require a shorter lead times for product development. A large portion of the market is often captured by the company that introduces the new product. The failure of a new product often constitutes a major financial setback.

PRODUCT DEVELOPMENT AT THE RERC-TET

The RERC-TET has many constraints similar to those of a small company. The crucial task for both is the application of a methodology by which target product specifications are derived from the initial device concept, customer requirements, technical input and knowledge of the product market.

The Quality Function Deployment model is similar in many respects to the methodology developed at the RERC-TET. Our methodology differs from the traditional QFD method in that very few new product attributes are known before-hand, and most of the features are customer driven. This issue was explored and a case study was presented by [6].

Assumptions underlying the QFD model include:

1. Use of a multi-disciplinary product team approach
2. Customer needs and expectations are well understood
3. Product market is well understood
4. Device concept is well understood from a technical perspective
5. A *majority* of product specifications are static while customer needs and expectations are drive a *minority* of the device specifications.

A close inspection of these assumptions is warranted. The first assumption requires product teams rich in expertise and personnel. The RERC-TET, like small companies in general, cannot easily and efficiently muster these kind of resources. The second assumption requires access to a large, well characterized customer population. Characteristics within a disability population are notoriously non-uniform. The problem is exacerbated when a device concept addresses needs across disability populations. The third assumption is problematic in that the initial device concept often lacks significantly in its ability to meet customer needs and therefore serves as an unsure probe of the competing product market. The fourth assumption implies that product specifications are being refined rather than "discovered." In general, for the RERC-TET, the opposite is true. The fifth assumption implies that a large market exists for a product if only "it better met customer needs than competing products." The QFD methodology is not generally used to steer a product to a niche market. In contrast, the market for assistive devices is generally a niche, and successful transformation of a device concept into a market product is necessarily steered by this recognition.

In spite of the fact that all of the QFD assumptions are somewhat challenged, the benefits of a QFD-like approach are obvious and overriding.

Method

Device concepts submitted to the RERC-TET are screened to establish whether the device concept meets significant customer needs, is technically feasible and has a significant market. Expert consultants often clarify issues not resolvable by internal expertise [5]. If the device concept is found to have merit, a device prototype is requested from the inventor.

At RERC-TET, product development follows a well-defined process. A multi-disciplinary product team, having at a minimum, customer, technical, commercialization and market expertise, is formed to determine the specific actions needed to transform the device concept into market product. Following an initial study, timelines, deliverables, possible outcomes and individual responsibilities in the team process are established.

Deficiencies of knowledge, expertise and infrastructure have been met by the development of a reference library whose titles cover manufacturers, distributors and standards for assistive and related products, identification and use of expert consultants, sub-contracting difficult fabrication problems, and partnerships with other research centers.

A customer focus group is generally run on the alpha prototype at this point to obtain customer input and direction. Product attributes are captured in a matrix, and *Idealized* device attributes are determined. This ideal device is then used as a benchmark for competing products existing in the market. Competing products ratings against the ideal device attributes are entered into the matrix. Important attributes missing from these products are identified and define an open target market.

VIRTUAL PRODUCT MODEL

Efforts are started to commercialize the virtual device. The rational for such an early attempt is that a company may have the resources, capital, expert knowledge and wherewithal to expedite the transformation of the virtual device into a market product. In addition, companies provide valuable technical and market knowledge. If at any point hereafter, the product team feels the device to be well characterized, and an interested company is identified, the device and all relevant information is transferred over to this company.

The identified attributes are converted into device specifications that best meet the needs of the customer opulation while establishing a market not met by competing products. Engineering drawings are then generated. Limited technical expertise sometimes forces the RERC-TET to subcontract work out. Constant interaction with the subcontracting company is then essential. The design process is constrained by materials selection, design of appropriate mechanisms, and manufacturability. Beta prototypes are then developed using available materials while adhering as closely as possible to specifications. Limited fabrication infrastructure further challenges the technical ability of design engineers, and impacts the choice of fabrication processes.

Customer focus groups are run on completed beta prototypes to identify and prioritize, general and specific device attributes further prescribing the "idealized device.". Technical and market input contribute focus group questions and subsequently help to interpret focus group outcomes. Competing products are again identified and evaluated against the idealized device attributes. Beta focus groups are conducted and an iterative refinement process established. If at any point the product team believes customer requirements are well met by a product or collection of products already on the market or that a viable market cannot be found, the inventor is informed of all relevant discoveries and the product team for this device is dissolved.

CONCLUSION

The methodology developed at the RERC-TET for transforming device concepts into market products has been successfully applied to a number of devices. Refinement of this methodology is an ongoing area of research.

ACKNOWLEDGMENT

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SIG-08
Sensory Aids

Design of a Haptic Graphing System

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ABSTRACT

Interpretation and understanding of complex scientific data is enhanced by graphic representation. Haptic display of such graphical data adds kinesthetic feedback that further improves, or allows conceptualization. In this paper, we present a method for the haptic display of two dimensional data plots using a three degree of freedom force feedback device linked to a speech synthesizer to aid in navigation. This system is designed to benefit visually impaired and blind persons, as well as sighted scientists, teachers and students who need or desire an alternate means to explore information traditionally displayed visually.

BACKGROUND

The use of computers to model complicated sets of data into a sensible form is a concept that dates back to at least 1960. Visualization of information is becoming generally recognized as an important tool, and a major application of Virtual Environments (VEs) in a society undergoing a dramatic explosion of information. Many people are discovering that visual techniques (e.g. computer graphics), combined with additional auditory and/or haptic channels, allow the conversion of complex information into a more easily understandable format (1,2).

In the past, this involved the common sight of the two dimensional plot of data points onto a two dimensional surface such as graph paper. At best, the projection of three dimensional data onto some form of two dimensional display such as a computer screen helped with data interpretation. Basic research into tactual perception indicates that the introduction of kinesthetic information, such as that provided by a haptic display, increases an individual's ability to perceive and understand nonvisual information, which is especially beneficial for those individuals without sight (2,3).

SYSTEM DESIGN

The haptic graphing system consists of three major components: the haptic interface hardware, the graphing system software, and the speech synthesizer.

The hardware being used is the PHANToM Haptic Interface from SensAble Devices, Inc. (4) This device generates forces on a stylus, or on the user's fingertip in a thimble. Both the thimble and stylus are attached to a gimbal mechanism allowing three rotational degrees of freedom. For this system, the stylus is used, especially since it includes a switch for user input. The forces are actually only generated at a point (the Interface Point (IP)) which is located at the intersection of the three gimbal axes. The nominal position resolution within the 8x17x25 cm workspace is 0.07 mm, allowing higher spatial frequencies (e.g., a crack can be felt that is less than 0.5 mm wide). Bandwidth constraints dictate the stiffness of virtual objects and the dynamic range of forces (the control loop bandwidth is asynchronous at about 3 kHz). The position sampling rate, or rate that the program can run, cannot be less than 800 Hz. Hardware instability may arise in the form of uncontrolled oscillations if these constraints are not adhered to, but these oscillations may occur from other sources. With this device, the user can feel the lines or surfaces of a data plot that would traditionally be represented only graphically.

To aid in navigation and understanding of the data, the Text To Speech (TTS) system developed at the Applied Science and Engineering Laboratory is utilized to speak the current location (data value) on the plot. Any other additional information can also be accessed if necessary. Due to the bandwidth constraints of the PHANToM, in addition to the fact that the PHANToM runs on a PC and TTS only runs on Unix systems, TTS is accessed via TCP/IP and sockets. The lag time for this communication is minimal.

DEVELOPMENT

The development focuses on taking advantage of the quality and versatility of the haptic interface. As a first step towards haptically rendering an *n* dimensional data set, a two dimensional, haptic graphing system is designed. The two dimensional plot is defined on a virtual wall, hereafter known as the plot wall. All virtual walls are defined by the plane equation
$Ax + By + Cz + D = 0$. Due to the bandwidth constraints mentioned above, the force calculated is proportional to the distance of the IP into an object surface (the spring model $F=kx$). Once the wall is placed, the origin of the graph is selected, which provides the matrix to transform the data into the coordinate system of the haptic interface. Ideally, a

haptic plot can be added to any virtual environment, so a bounding box is placed around the graph for basic collision detection, which determines force vectors. In this manner, collision detection for the individual graph items is not computed until the IP is within the bounding box, therefore saving valuable computation time within a complex VE.

The data to be plotted can be produced by any software that can output an ASCII text file containing pairs of [*x*,*y*] data points. The previously calculated transformation matrix is then used to determine the location of the data points in the haptic environment, located on the plane of the plot wall. It is not necessary to render the entire data set since the IP can only contact one point on the data curve at any given instant. A linear interpolation of the data determines the piecewise linear segments that are rendered when the IP is between any two abscissa values. For example, say that there are data points with abscissa values at 1, 2, 3, and 4. When the IP is inside the bounding box, and between points 2 and 3, only the line between 2 and 3 is active, as seen in Figure 1.

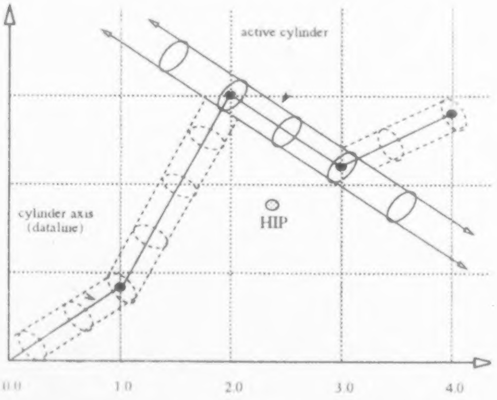

Figure 1: Front view of plot (HIP is Haptic IP)

Recall that the force generated by the application acts on a single point. This force is typically proportional to the distance of penetration into the object by the IP, similar to the wall representation. Since a line has no volume, the graph lines are represented in three dimensions with cylinders or planes.

Given that the graph segments are represented using cylinders, calculation of the ends of the cylinders, which would occur at each data point, is unnecessary since the adjacent cylinder becomes active immediately after the IP crosses a data point abscissa value, as Figure 1 displays. However, considering the IP is a single point, it is very difficult for a human operator to locate and follow thin cylinders in a 3D environment, especially without a visual representation. This concept has been demonstrated through experimentation. A simple solution would be to increase the cylinder radius; however, this may lead to slight ambiguity if the radius is too large, which is essentially a low resolution condition.

The method used to give a more accurate representation of the data that can easily be found in the VHE is based on the virtual fixtures metaphor (5,6). By using virtual fixtures, the cylinders can have a larger radius that make them easier to find. Once the IP breeches the cylinder surface, force cues are generated to move the IP to the axis (data line), much like a "snap-to-grid" function seen in many computer drawing packages. These forces are a function of the distance from the IP to the cylinder axis. Therefore, the user is guided along the data line since the only forces generated are perpendicular to, and toward this line. The weighting functions used to accomplish this is a modified version of the function described in (6). This function is given by

$$W(d) = C\left(1 - \frac{1}{1 + k_1 d^{k_2}}\right)\left(\frac{1}{1 + l_1 d^{l_2}}\right)$$

where C is a scaling constant, and k_1, k_2, l_1, and l_2 determine the "feel" of the fixture, and d is the distance to the data line or axis.

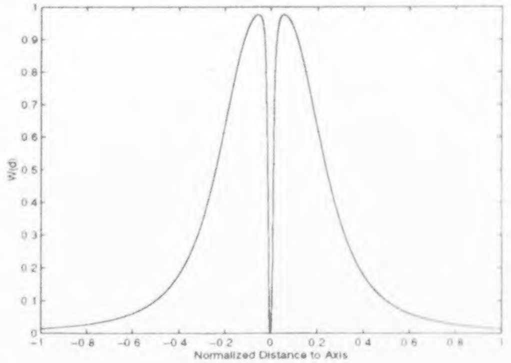

Figure 2: Cross-section of data cylinder force profile

Figure 2 shows a cross-section of a cylinder with a typical weighting function that has been successfully implemented. The left half of the equation is used to prevent instability of the hardware by preventing an instantaneous change from no force at $d = 0$, to a force of C at $d > 0$. Instability occurred because a human operator can not keep the IP exactly on the axis. In other words, when the human is taken out of the loop, the system is stable because there are no external forces to move the IP from the zero force line to the

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relatively large nonzero force region. The multiplication of the left component effectively creates an axis that has a small radius where no forces are generated, with a continuous transition (vs. discrete) to the nonzero force region.

Again, considering that zero volume lines cannot be found by a zero volume point, the plot grid lines and axes are represented by planes that are orthogonal to the plot wall. The axes planes are rendered as "stiff" walls so that forces are not generated until the user attempts to move outside the plot area on the plot wall, which eliminates interference with the forces due to the data lines. It is also important that the grid "planes" do not interfere with data interpretation. Thus, the grid "planes" actually have a nonzero depth (they are thin rectangular parallelepipeds) which produces viscous damping when the IP is within them. These "planes" also extend to the bounding box. When the IP moves through these regions, a force is generated normal to the grid surface, and proportional to the IP velocity in the negative direction. This results in the common damping equation ($F=-Bv_n$, where B is the damping coefficient, and v_n is the velocity component normal to the grid plane). Experimentation found that the implemented method is unobtrusive and adequate to represent grid lines. This concept can be easily extended to a 3D graph as intersecting planes in three orthogonal orientations.

At any point on the plot, the user can press the stylus switch, which will activate the speech synthesizer. The TTS is sent the grid coordinates (with respect to the graph origin), which are consequently spoken to inform the user of the current location on the plot. Therefore, all relevant information about the plot can be obtained in a non-visual fashion.

DISCUSSION

Simple plots (i.e., a small number of data points) have been represented with this system. The addition of the non-obtrusive grid and axes representations are necessary in a haptic rendering just as they are in a graphical rendering. This is also true for the values of the grid. The simplest solution for this is to take advantage of the sense of hearing. It would be difficult to represent Braille characters since the user could only feel one dot at a given instant with the PHANToM.

FUTURE WORKS

This system represents a method of haptically rendering data plots; however, experiments to prove that complex information can be comprehended in this fashion have not been performed. The limit on how much data can be represented in one plot before ambiguities occur must also be determined. Extending this representation to three dimensional data (e.g., mesh plots) is planned as well. This extension would involve representing surfaces or a method of giving the IP a third dimension (by placing a sphere around it) in order to feel discrete data points. The latter method can be thought of as a morphological structuring element similar to that used in morphological filtering for image processing.

CONCLUSIONS

The design of a haptic graphing system has several goals. It allows access to data plots by individuals who cannot view them in a graphical manner. Haptic rendering of two dimensional data using the concepts discussed in this paper will lead to improved conceptualization of complex information. The general population can also benefit since research has shown that the addition of another sensory input can enhance comprehension of complex information.

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Towards Automatic Generation of Tactile Graphics

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Abstract

Abundant high-quality computer images are available on the Internet and elsewhere, yet many are virtually inaccessible to the blind computer user. This paper introduces research in the development of a system for automatic conversion of any digitized image into a comprehensible tactile graphic form. An experimental software and hardware system is presented, and preliminary test results are discussed.

Background

The explosive growth of reliance upon the graphical user interface (GUI) has had significant impact on computer users, nowhere more negatively than among blind users. Some barriers can be overcome by use of new commercial GUI-friendly screen review and speech synthesis software and hardware in combination with standbys such as embossed braille printers and braille cell displays. Experimental approaches include the use of multimodal interfaces using audio and/or tactile output (5, 8), and the development of a variety of dynamic tactile display technologies, which is vigorously underway, though it may be some time before these directly impact users (1).

Haptic perception of tactile graphics is improved when issues such as resolution of the fingertip, image size, exploration mode, image complexity, and the dependence upon simultaneous kinesthetic and cutaneous stimulation are accounted for as demonstrated in (2, 4, 9). Those studies, and others like them, combine to point out the complicated interdependency among numerous factors in the development of a tactually legible tactile graphic display.

This paper describes research into the development of a system which attempts to take into account many of these issues. This system uses image processing techniques to simplify a complex computerized image, such as a photograph, and subsequently produce a tactile representation through an output medium such as microcapsule paper. The goal of this study, and the system we are developing, is to identify techniques for producing meaningful tactile graphics from the wealth of on-line visual graphic information, and to ultimately create a usable software and hardware solution to that end.

Research Question

Translation of complex images into tactile graphics which are meaningful to a blind person clearly requires some type of simplifying transformation. There are numerous image processing algorithms that segment images, locate region edges, reduce noise and generally extract meaningful features. Applying various combinations of these processes produces a broad range of results. Determining, in an automatic fashion, the optimal aggregate process, which may even be image dependent, is our aim. This preliminary study tests the efficacy of a small subset of image processing algorithms on the ability of sightless subjects to recognize identical images from a closed set.

Method

The experimental system consists of both software and hardware. The software is implemented in the C programming language as an extension to the X-windows image processing application "XV", developed at the University of Pennsylvania, running on a SUN Sparcstation 20. Our initial extension includes additions of new algorithms for grayscaling, negation, K-means clustering, and a Sobel edge detector (3, 7). In this application, the K-means algorithm adaptively segments an image into black and white using a statistical analysis of luminance levels of the pixels. The Sobel edge detector recognizes changes in luminance in both the X and Y directions, and highlights places where the luminance changes quickly indicating the existence of an edge in the image.

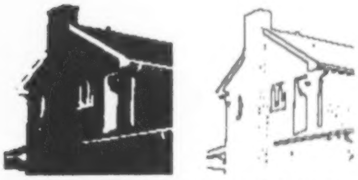
The hardware component is a Reprotronics Tactile Image Enhancer, which produces raised tactile graphics on Flexi-Paper, a cloth-based microcapsule paper also developed by Reprotronics. Additional components include a 300 dpi Hewlet Packard IIISi laser printer and a Lanier 6725 photocopier. Note that any combination of laser printer and copier should work equally well, with the consideration that the photocopy machine must handle the slightly thicker capsule paper without jamming.

We collected eight digital images found on the Internet as our test set. The set of images are photographs of three different faces, the chimney of a house, a notebook computer, a hot air balloon, a space shuttle launch, and an illustration of a human heart. These were selected to provide a variety of image types yet similarities among various subsets of the group. That is, the three faces, hot air balloon, and human heart illustration have similar (round) overall shapes, while the notebook computer and house are characterized by straight lines.

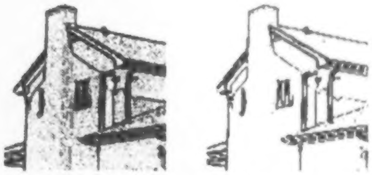
Tactile Graphics

Each image was processed five different ways, using grayscaling alone and in combination with either 2-way K-means clustering or Sobel edge detection or both, and in both possible orders. For each combination of processing the eight resulting images were printed out in the same size (2.5" x 2.5"), and randomly arranged on a single blank sheet of paper.

Example of an original grayscale image



K-means(2) without & with Sobel Edge



Sobel Edge without & with K-means(2)

A second sheet was similarly prepared using the same processed images in a different random arrangement. Subsequently, these sheets were photocopied onto capsule paper and raised using the enhancer. The above five figures illustrate the progression of processing undertaken.

Four sighted subjects were blindfolded and asked to perform a matching task. First, a subject's hand was placed onto one processed image on one of the sheets, and the subject was allowed to freely explore the image. Then, the subject's hand was guided to a random spot on the second matching sheet and the subject attempted to locate the identical object on this second sheet. This task was repeated for each of the eight images on each of the five pairs of identically processed sheets.

Results

Table 1 contains the results of this experiment. The Table columns indicate the type and order of image processing used, the average number of matches out of eight per subject and the average percentage of matches per subject, for each of the algorithm combinations.

Table 1: Average Images Matched

Image process	Matches	Pct.
grayscale	2.25	28%
and K-means	6.25	78%
and Sobel	4.75	59%
and K-means & Sobel	5.75	72%
and Sobel & K-means	7.75	97%

Discussion

Clearly even a small amount of simplification yields a marked improvement in tactile image recognizability. Images which were simpler at the outset were recognized more easily in all cases. In particular, an illustration of the human heart chambers and a photograph of an open notebook computer tended to be distinguishable even with no processing, probably due to a white background and simple initial representation. There was often confusion among three images of human faces and a hot air balloon, each of which has an essentially oval shape. Even though there was a general tendency for recognition to increase when images were simpler, no statistically relevant conclusion can be drawn about the efficacy of line drawing versus light and dark region representations, nor can anything be said about identification of the content of the images.

However, some interesting anecdotal evidence was gathered. Some subjects reported, upon feeling the processed images, that they thought there was more than one face among the images, though none had any idea ahead of time as to the content of the images. This content identification was not reported upon feeling the original unprocessed images.

The tactile pattern identification methods observed during the experiment are also interesting, and intuitive. The tendency among all subjects was to use the outside edges of an image for gross classification. Once gross classification was determined, the details found through careful exploration of the interior of the images were used to separate similar images from on another.

Overall, we feel that the results strongly indicate that this method is valid and deserves further investigation.

Future work

We plan to extend our study in a number of ways. First, improved algorithms which provide reasonable results for a broad range of images must be utilized or developed. One possibility we are considering is use of an adaptive clustering algorithm which produces a more accurate segmentation (6), although it is computationally expensive. Also, the use of tactile patterns must be investigated. Patterns may be an efficient way to represent regions of an image that have bee segmented. Clearly, study is warranted incorporating a larger set of images, algorithms and subjects. This study must look not only at identification, but content identification and understanding - access to content is, after all, what drives this research. Finally, we want to develop an application which can be invoked by other applications in replacement of a print routine, which will automatically analyze and simplify an image and send the result to a printer.

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DEAF-BLIND USERS GRASP THE IDEA WITH DEXTER, A PROTOTYPE ROBOTIC FINGERSPELLING HAND

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ABSTRACT

The intelligibility of a new version of Dexter, a robotic fingerspelling hand, was tested in its ability to display random letters and unrelated sentences. All five deaf-blind subjects (who range widely in their ability to read tactile fingerspelling) were able to read all, or almost all, of the random letters and the sentences displayed by Dexter. It was evident, however, that tactile reading of the robotic hand is much slower than tactile reading of a human fingerspeller. To increase speed but not lose intelligibility, we will modify some of the letter shapes as well as make Dexter's movements more similar to that of a human hand. We will also add telecommunication display capabilities.

BACKGROUND

Telephones, facsimile machines, and e-mail have made communicating with someone on the other side of the world almost as easy as communicating with someone in the same room. Because use of these technologies requires vision or hearing, they have not been generally accessible to most people who are both deaf and blind.

Deaf-blindness among adults is most commonly the result of a genetic condition called Usher's syndrome (1). Since the vision loss starts during the teen years, it is common for the Usher's syndrome child to be educated in a special program for deaf youngsters, and receive no preparation for the vision loss which inevitably occurs later on. The student learns to read print and to communicate via either sign language (including fingerspelling), or speech reading (a comprehensive expansion of lip reading). These are all vision-based skills.

The gradual vision loss often becomes severe enough that the Usher's patient can no longer see the hands which fingerspell, the lips which speak, or the print which is displayed on paper or TDD (telecommunication device for the deaf). New special skills must be learned to compensate for further reduced sensory input.

The most efficient solution for those with Usher's syndrome is to learn braille. For blind people braille serves as a medium for reading and for accessing computers; for deaf-blind people braille serves the additional role of communication tool. The most popular braille device which enhances the communication ability of deaf-blind braille readers is the TeleBraille. The TeleBraille is a TDD with a braille display, and can be used for either face-to-face communication or for telecommunication.

STATEMENT OF PROBLEM

Relatively few Usher's syndrome patients are able to take advantage of braille materials and displays. One reason is that most programs to teach braille are designed for, and available to, hearing children, not deaf adults. Also, there is typically great reluctance among those with Usher's syndrome to learn braille. Learning a new code designed for a less efficient modality is not appealing to individuals who are proficient in communicating via sign language and print. Using braille also has important emotional implications. It is perceived as the ultimate "admission" of blindness -- a difficult step for those left with even a small amount of vision.

The non-visual communication system of choice for those with severe vision loss from Usher's syndrome is usually a modification of the familiar: a hands-on version of sign language or of fingerspelling. Both methods have their drawbacks. Hands-on sign language is extremely awkward and fatiguing as it requires both hands of the interpreter to be in constant contact with both hands of the deaf-blind person. It also requires a lot of arm movement in space without the clear body reference points used in visual sign language. In contrast to hands-on sign language, tactile fingerspelling requires only one hand of the deaf-blind person to be in contact with one hand of the interpreter, and each person's hand may remain stationary. However, this method is tedious and time-consuming as each word must be spelled, letter by letter.

In addition to the constant physical contact demanded by hands-on sign language and tactile fingerspelling, both have several other limitations as well. They restrict communication to the small number of individuals who know these codes -- and are willing to employ them with someone who requires direct physical contact. Also, these communication systems do not give deaf-blind individuals access to written materials, computer displays, or telecommunications.

METHOD

To address the above problems, the RERC at The Smith-Kettlewell Eye Research Institute has engaged in collaborative efforts to develop a mechanical fingerspelling hand named "Dexter" (2,3,4)[1]. Dexter receives ASCII from an interfaced computer in response to messages typed to the deaf-blind user. As Dexter receives these signals, it forms the appropriate letters of the American one-hand manual alphabet of the deaf. By feeling these hand configurations deaf-blind individuals can "read" the messages being typed. In a similar fashion, Dexter can also provide the user with access to computer information.

The Smith-Kettlewell Institute is currently working with Upstart Robots in San Francisco to develop a commercial version of Dexter for both face-to-face communication and telecommunication (5). Toward this end we recently developed a new Dexter and evaluated its intelligibility. The testing was conducted with the assistance of five deaf-blind subjects whose tactile fingerspelling skills ranged from novice to expert. They were asked to read individual letters, as well as unrelated sentences, presented by Dexter. The letters were presented as alphabet sets, displayed randomly without replacement. The subjects were asked to read three such sets during one session. No time limits were imposed. The sentences were also presented three times.

RESULTS

Initial intelligibility for the 26 letters of the English alphabet, presented in random order without replacement, ranged from 20 to 26 correct. Based on instant feedback, we made slight modifications to some of the finger shapes during sessions. By the third presentation one subject correctly identified 23 letters, and four subjects correctly identified all 26 letters.

The confusion matrix in Figure 1 shows the subjects' responses for each of Dexter's 15 presentations of each letter (three complete sets for each of 5 subjects). A column total of more than 15 indicates that a subject gave more than one response; totals of fewer than 15 indicate at least one individual did not make a response. The table shows that only one error was made in the reading of letters B, C, G, I, J, L, R, S, and Z; two errors were made in reading letter A; five in reading P, and five in reading Q.

Dexter's presentations of ten unrelated simple sentences were also highly intelligible. In almost every instance the deaf-blind users were able to accurately recite all, or almost all, of the words in the sentences.

DISCUSSION

An analysis of the nature of the few letter errors gives useful insight regarding what is needed to improve the hand. For example, both P and Q are made with downward wrist flexion. While Dexter is capable of this movement, the pressure of some of the users' hands prevented it from completing this action. The fact that in four instances the letter Q was mistaken for G, is an example of this problem.

Sentence-reading errors seemed related to memory overload from the time needed to recognize letters displayed by an unfamiliar device, rather than to errors in identifying the letters. Receiving tactile information from a mechanical hand appeared to require much time and concentration. The increased time and effort of reading a mechanical hand is added to the heavy memory demand of fingerspelling in general: recognize each letter, retain the sequence of letters, blend these to form a word, retain the sequence of words, and finally blend the sequence of words to form the entire sentence.

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[1] This concept originated at the SouthWest Research Institute, San Antonio, Texas. Smith-Kettlewell's original collaborations to develop a modern hand were with students from the Department of Mechanical Engineering at Stanford University.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	14																		1							
B		14																								
C			13																							
D				15																						
E					15																					
F						15																				
G							14									2	4									
H							1	15																		
I	1								14	1																
J										1							1									
K											15					2										
L												14														
M													15													
N														15												
O			1												15											
P																11										1
Q																1	11									
R																		14								
S																			14							
T																				15						
U																					15					
V												1										1				
W																							15			
X																		1						15		
Y	1								1																15	
Z																										14

Letters Presented By Dexter

Figure 2. Confusion Matrix of Random Letters Read Tactually by Deaf-Blind

FUTURE PLANS

A detailed analysis of the number and types of errors made in the transmission of letters and sentences to the five deaf-blind subjects, the researchers' observations about the transmission process, and subjects' comments about the device, are guiding the anatomical and functional design of a new hand. The finger positions to form some of the letters will be slightly modified, and some of the dynamic aspects of Dexter's performance will be altered to make them more like those of a human interpreter. These improvements are expected to make reading the hand faster and less demanding, especially in real-life situations where relevant sentences appear in meaningful context. In addition, Dexter's usefulness to the deaf-blind community will be expanded by adding telecommunications capability to the next generation of this system.

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LIGHT/DARK-ADAPTING EYEWEAR FOR PERSONS WITH LOW VISION

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ABSTRACT

The purpose of this project is to research, develop and evaluate eyewear that dynamically and "instantly" darkens/lightens to control the amount of light reaching the wearer's eyes. Final engineering prototypes will be evaluated by 104 subjects in a side-by-side comparison with each subject's preferred sunwear. Both clinical trials and outdoor mobility trials will be employed. The results of these trials (differences in acuity and contrast sensitivity under glare conditions, differences in walking pace and obstacle avoidance, and differences in subjects comments) will be evaluated relative to each of four low vision populations, along with recommendations for optimal device construction and manufacture. This will be presented in major conferences and distributed to potential manufacturers. An initial retail price of about $200 is expected.

BACKGROUND

Persons with ocular diseases such as retinitis pigmentosa (RP), albinism, aniridia and achromatopsia have extreme problems with varying light conditions and can usually function effectively only under controlled lighting conditions. Other ocular diseases such as macular degeneration and conditions affecting the ocular media (e.g., cataracts, corneal dystrophy) have varying effects on retinal adaptation. Dark adaptation times as long as 30 minutes are not unusual [1].

For all persons (fully sighted as well as persons with low vision), a fairly narrow range of overall illumination is optimal. Too much or too little light results in dramatic reductions of visual acuity and a corresponding reduction of visual function [2]. However, the unimpaired person has a type of visual reserve (i.e., more acuity, more field of view, more contrast sensitivity, more light/dark adaptation, etc. than the minimum required by the visual task) [3] that gives this person the ability to maintain functional performance in less than optimal conditions.

A fully sighted person exiting a darkened theater into bright sunlight may squint, shade the eyes, look down, etc. until the eyes have adequately adapted (only a few minutes); however, this person *can* continue to function while adapting to the sudden change in lighting and *will* be able to avoid obstacles and negotiate curbs and stairs. But the low vision traveler, who does not possess this reserve, can*not* function under these circumstances.

The low vision traveler experiences two primary functional vision problems: detection of changes in terrain (such as curbs), and adapting to changing lighting conditions [4]. In a recent national survey, low vision consumers and their mobility instructors rank-ordered their most serious orientation and mobility problems. "Changing environmental lighting conditions" was considered the most difficult mobility situation by both consumers and instructors [4]. "Drop offs," down curbs and steps, were reported as second most difficult. Persons with low vision were also found to confuse shadows of buildings and mailboxes with curbs and potholes. In terms of functional mobility, this confusion resulted in reduced travel speed and gait changes based on reactions to shadows [5].

Restricting the amount of light reaching the low vision person's eyes to a set upper limit might, in and of itself, provide a sufficient increase in acuity and contrast sensitivity to distinguish between a shadow and a "drop-off." However, while "static" sun lenses or individually prescribed illumination-restriction devices may alleviate some of this difficulty, this type of eyewear does not eliminate the variability in visual functioning brought on by ever-changing [rapidly changing] lighting conditions" [4].

Light-absorbing lenses are available and prescribed in a variety of styles, colors and levels of light transmission. But in order to adapt to a variety of conditions (bright sun, cloudy, indoor bright, indoor dim, fluorescent or incandescent lighting) it is necessary for low vision consumers to find a variety of absorptive lenses and illumination controls, and to change back and forth among them—a rather cumbersome task. Photo-darkening lens coatings have been available and do provide a degree of accommodation to changing lighting conditions. However, the photo-chemical processes currently employed do not adapt "instantly" to changing lighting conditions, especially when going from bright sunlight into shadow—a particularly hazardous situation for persons with low vision. Further, the wearer cannot control this photo-process to effect a light level that best suits his/her individual needs.

The concept of "ideal retinal illumination level" emerges from the physical property of optimum stimulus threshold for the eye, which is dependent upon a variety of factors (such as ocular health status, age, and task). Therefore, the development of eyewear that dynamically and "instantly" adjusts to restrict the amount of light reaching the eye to a brightness close to the "ideal retinal illumination level" should significantly contribute to visual functioning.

RESEARCH QUESTIONS

Two research questions are to be answered by this research.

1. If dark-adapting sunwear were available, under "typical" indoor and outdoor ambient lighting conditions, what light to dark transmission ranges would optimize the visual performance of the following low vision populations: (a) persons with central vision loss from age-related macular degeneration, (b) persons with cloudy ocular media and (c) persons with rod/cone dystrophy; where visual performance is defined in terms of (i) acuity and contrast sensitivity measured under both glare and non-glare conditions, (ii) outdoor mobility performance, and (iii) subject comments?

2. To what degree can existing technologies be employed to produce adaptive eyewear that effects these light to dark transmission ranges (a) in less than 300 milliseconds, (b) for prescription plastic eyewear, (c) without increasing weight placed on the nose by more than one ounce, and (d) at a reasonable cost (less than $250); and, does this significantly increase the functional vision of the above populations?

METHODOLOGY

This research has and is being conducted in six stages:

1. An initial evaluation of available light-control technology materials/ techniques has been performed.

2. Two initial prototypes were designed and constructed employing the most promising of the available materials at that time. To meet the weight requirements and minimize the cost of these initial prototypes, the electronics and batteries were placed in a small box that clipped to the wearer's belt.

3. The two initial prototypes were compared to the preferred sunwear of 22 subjects in (a) a battery of clinical vision tests (acuity and contrast sensitivity under glare and non-glare conditions), and (b) outdoor functional mobility trials. The purpose of these tests was to informally begin to answer the two research questions. Subject observations and comments were solicited and recorded.

4. The informal test results (including subject observations and comments) were analyzed and sorted by disability category and frequency. Design of the final prototypes is based on these results.

5. The final prototypes will be evaluated by a population of 104 subjects in a comparison test among each subject's preferred sunwear and each of the two designed prototypes . The subjects range in age from 55 to 75 years and are comprised of four sub-groups: (a) 26 "normal" subjects, (b) 26 subjects with central vision loss from age-related macular degeneration, (c) 26 subjects with cloudy ocular media, and (d) 26 subjects with rod/cone dystrophy.

6. Results will be analyzed relative to each subject grouping Qualitative elements of the above tests will be descriptively presented through measures of central tendency and dispersion. Tabulation and graphic representations will be employed when appropriate. The objective data will be evaluated with multiple paired t-tests or repeated measures ANOVA to identify main effects and interactions of condition by device. Subjective data will form the basis for specific case studies that will complement the objective findings by identifying specific examples of advantages and disadvantages of the eyewear. The 104 subjects employed for the final testing will provide more than adequate power (>.99) to differentiate among factors, and will give adequate power (>.85) for differentiating among the four sub-populations.

Significant results will be published and presented at low vision conferences. Design recommendations along with population information will be provided to interested manufacturers.

RESULTS

Two technologies were initially investigated for light control: Liquid Crystal (LC) and Electro-Chromic (EC). However, the first prototypes employed only LC technology, because EC technology at that time could not darken below 15% transmission — our initial goal was 1% transmission. As of this writing, though, new EC materials have been developed that are much more competitive. Two final prototypes are thus being developed at this time for final subject testing: one employing LC technology and one employing EC technology.

Initial subject testing yielded two important results. First, from subject responses it became evident that the equipment employed to measure prototype light transmission ranges in the laboratory was not adequately indicating percent transmission as perceived by the user. This lead investigators to analyze spectral issues and angular field of view issues. As a result, a means of measuring the amount of perceived light at the eye was developed and is now employed to evaluate prototypes.

Second, subjects complained that when going out of doors, the prototypes darkened immediately and completely, and then did not respond to further increases in ambient light intensity. The investigators discovered that this phenomenon was caused by the controlling electronic circuit. This circuit was designed to maintain a constant level of light at the user's eyes. Most subjects preferred a light level at their eyes in the range of 6 to 12 relative units when engaged in indoor testing. On a bright day, outdoor light levels can exceed 1000 units. When the circuit was adjusted to admit no more than 10 units of light, because the lenses can darken only to 5% transmission, they will darken completely and immediately on going outdoors whenever the light intensity is above 200 units, and thus any additional brightness will not be mediated. The investigators thus changed their original goal of maintaining a constant level of light at the wearer's eyes. The modified goal stated that the desired eyewear would restrict the intensity of light at the wearer's eyes to a specific range of approximately 10 to 40 units, and that changes in light intensity at the wearer's eyes would always represent much larger changes in ambient light intensity.

DISCUSSION

The planned final LC prototype (currently being constructed) employs a nematic LC material with a guest-host dye added to it. This guest-host dye, when aligned in rows by the nematic LC molecules, acts as a polarizer. When a voltage is applied the molecules are pulled out of alignment, and polarization is lost. A "flip-down" polarizer is employed with these lenses that will effect an overall light to dark range of 72% to 3.7% transmission in two sub-ranges. First, with the polarizer "flipped up," an "indoor" range of 72% to 38% will be effected. Second, with the polarizer "flipped down," an outdoor range of 26% to 3.7% will be obtained. Tests of this neutral gray LC material shows that it darkens very quickly (12 milliseconds), produces no visible optical distortions, and reduces ultraviolet radiation by almost two orders of magnitude.

An EC prototype is also to be constructed. The characteristics of the EC material to be employed have not been tested by the investigators as of this writing. The company devising these materials claims they can achieve a light to dark range of approximately 80% to 3% and a darkening time of 1 second or less. Optical clarity is also an issue that must be resolved by the investigators.

The control circuit for the final prototypes will be modified to implement the new goal stated above. The new circuit will allow the amount of light reaching the wearers eyes to increase slowly with the actual light increase, but in much smaller increments. Outdoors, as light varies in a range from 50 lumens to 1000 lumens (a 20 times increase in intensity), the wearer will perceive a change from 10 to 35 lumens (merely a 3.5 times increase in intensity).

Final subject testing is expected to commence in mid May, 1996.

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AUDIBLE INDICATOR FOR GUITAR TUNER

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ABSTRACT

As a result of severe visual impairment a professional singer and songwriter, well known in RESNA circles, was unable to see the LED indicators on an electronic guitar tuner. A simple circuit was designed to be built into the tuner to monitor the LED drive circuits and generate a corresponding audible indication in an earphone. The implementation was successful and, with appropriate modifications, should be generalizable to other items using LED or incandescent lamp indicators. A circuit diagram is available.

BACKGROUND

People with severe visual impairments generally find it either difficult or impossible to use common items that utilize visual indicators. In this case, a professional singer and songwriter who is legally blind wanted to make use of a small handheld portable battery powered electronic guitar tuner[1]. This is an especially valuable device in particular situations, such as when tuning in a noisy environment. The tuner has LEDs to indicate the string being tuned (one of six) and whether the tone is FLAT, SHARP, or IN TUNE. If no note is detected, then none of the tuning LEDs are lighted.

STATEMENT OF THE PROBLEM

The singer was able to tune each string to the general desired tone, and thus did not need to have an alternative indication of the notes. However, he did want to have an alternative indication of the FLAT, SHARP, and IN TUNE LEDs.

RATIONALE

A system was proposed to the singer in which he would use an earphone to listen for audible indications of the tuning LEDs. Each LED would produce a different tone in the earphone. The IN TUNE LED would produce a pleasant middle C range tone. The FLAT and SHARP LEDs would produce correspondingly lower and higher tones. The singer agreed to proceeding with a prototype design.

In addition to the basic function, design criteria included ease of use, construction inside the enclosure, low battery drain, low cost, and ease of replication.

DESIGN

The tuner was opened and the power and LED drive circuits were traced. The unit was powered by a nine volt battery with a five volt regulator supplying power to the digital circuits. It was proposed that the tone generating circuit be powered at the five volt level in order to take advantage of the system for powering up and back down, which happens automatically after a preset time.

The three subject tuning LEDs were driven by low true circuits. Of course, only one would be on at a time and with no note being detected all three would be off. A common CMOS low power timer circuit was selected to implement the function.

DEVELOPMENT

Even though the tuner was small, the enclosure had ample open internal space. The "freespace" circuit was attached to the tuner circuit board and wired to the power and LED drive circuits. An earphone jack was added. In addition to the three tones, a very low frequency ticking is a reminder that the power is still on when no tone is being detected.

EVALUATION

The completed unit was evaluated by the singer. He has commented repeatedly that, for the first time since losing his sight, he has the pleasure of playing a virtually perfectly tuned instrument. He refers to the solution as elegant in that it provides the desired function with essentially no additional demands on him or other adverse effects.

DISCUSSION

The manufacturer of the tuner was contacted and an agent indicated that they receive occasional requests for modifications of this nature. The design is being shared with them.

With appropriate modifications, the design should be able to be implemented on other devices that use LED indicators.

A circuit diagram is available by contacting the author.

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SIG-09
Wheeled Mobility and Seating

FORWARD DYNAMIC STABILITY TEST FOR MANUAL WHEELCHAIRS

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ABSTRACT

In the interests of wheelchair safety and design, we have developed a simple, repeatable test that can be used to determine the forward dynamic stability of a wheelchair. This is done by measuring the wheelchair's ability to handle a common riding situation: hitting a low obstacle while rolling down a sloped plane.

Test methods included creation of a variable-height wheelchair obstacle and means of guiding a rolling wheelchair and accurately determining its speed. An anthropomorphic test dummy was used.

Seven different wheelchairs and/or configurations were tested, and the results confirmed that the test is repeatable and can be used to quantify differences in forward dynamic stability between 1) different wheelchairs, 2) different rolling speeds upon impact with the obstacle, and 3) different types of caster wheels installed on the same wheelchair.

In the quantitative results there were no differences between the dummy being belted versus not belted into the wheelchair seat.

INTRODUCTION

Epidemiologists have acknowledged that adverse wheelchair riding incidents are a significant problem and that the majority of serious wheelchair rider injuries result from tipping or falling out of the chair (1-4). This highlights the limited stability of current indoor/outdoor wheelchairs. One avenue for addressing wheelchair safety has been wheelchair testing and the publishing of American National Standards Institute (ANSI)/RESNA and International Standards Organization (ISO) wheelchair testing standards (5). The standards do not yet include tests of dynamic stability for manual wheelchairs.

METHODS

The basic test

The wheelchair, loaded with a test dummy, was rolled down a 5° sloped plane. At a specified speed of travel, its front wheels hit a low, rigid obstacle. A test observer noted whether the wheelchair overcame the obstacle or tipped forward, or if the dummy fell out of the seat. (For this test, a tip was defined as the wheelchair tipping far enough that one or both footrests touched the test plane, or the wheelchair tipped over.) If the wheelchair overcame the obstacle with no tip or dummy fall, then the test was repeated with an obstacle of incrementally greater height. This procedure was repeated until eventually tipping and/or falling were observed. The primary result for each wheelchair, at each tested speed, was the height of the largest obstacle that did not cause the wheechair to tip or the dummy to fall out.

The obstacle

The variable-height obstacle was built up using 1/4 in. (6 mm) thick, 3 in. by 48 in. (80 mm by 1,200 mm) rectangular pieces—an aluminum top step and plywood understeps. These were bolted to the asphalt test plane, across the path of travel (**Figure 1**). The aluminum top step had one rounded edge where it first contacted the oncoming wheelchair (radius = 1/4 in. or 6 mm). The plywood understeps were slotted at the mounting bolt locations, so that they could be easily added or removed to adjust obstacle height incrementally from 1/4 in. up to 3 in. maximum.

Generating wheelchair rolling speed

Each wheelchair (or configuration thereof) was tested at two rolling speeds, 3 and 6 mi/hr (1.3 and 2.7 m/s). To generate and control wheelchair speed we released the wheelchair from a standstill—using only gravity to accelerate it down the slope—and measured the speed immediately before impact. The impact speed was adjusted as needed by moving the wheelchair's starting position up or down the slope.

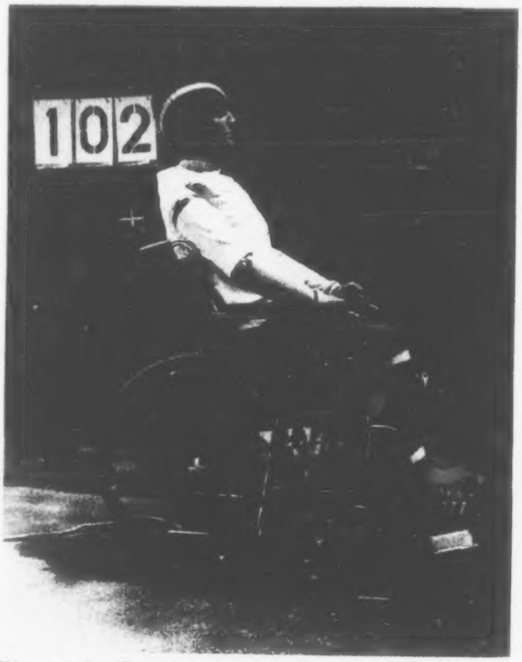

Figure 1. Test setup.

(This method was used in stability tests performed by Kirby et al (6).) We were able to set the test speed of 3 mi/hr to within ± 2%, and 6 mi/hr ± 1%.

Wheelchair direction control

To generate 6 mi/hr at impact with the obstacle, the wheelchairs needed to roll nearly 18 ft (5.5 m) down the test plane. A simple guide rail system was developed to insure that the wheelchairs' front wheels consistently struck the obstacle simultaneously.

The guide rail was a 7/8 in. diameter by 20 ft long (2.2 cm by 610 cm) steel tube, supported 11 in. (28 cm) above the test plane. A lightweight, low-friction guide arm assembly was attached to the wheelchair (**Figure 2**). This assembly was fabricated primarily of 3/16 in. (5 mm) diameter steel bar stock, a steel hinge, and nylon rollers (colored white). The hinge, at the wheelchair-end of the arm, allowed the roller-end of the arm to move vertically, so it could be lowered onto any part of the guide rail. A mounting cuff and stabilizing strut allowed easy, secure mounting on a variety of wheelchair frames, using common band clamps. The mounting location was usually on the wheelchair's footrest strut. Just before the wheelchair hit the obstacle, the roller assembly would run off the end of the guide rail, so the rail did not interfere with the collision.

Wheelchair speed measurement

Speed measurements were taken as close as possible to the time of impact with the obstacle, to minimize measurement error due to wheelchair acceleration. Our system measured wheelchair speed within the last 6.5 in. (170 mm) of travel before impact.

Returning to **Figure 2**, notice the secondary timer-trigger arm, mounted to the same hinge as the roller guide arm. It carried a 6.0 in. (150 mm) long black board that passed through a light gate. (The light gate was an infrared beam and optical sensor, appearing in the figure as a backwards-C-shaped item, mounted on a secondary rail). The timer (not shown) indicated wheelchair speed by measuring the time during which the board interrupted the light beam. An elastic cord attached to the timer-trigger arm minimized unwanted movement (play) in the hinge, to improve time measurement accuracy.

The use of 3/16 in. steel bar to fabricate the roller guide and timer-trigger arms allowed us to bend and align the assembly to fit a variety of wheelchairs, using only hand tools. The strength and stiffness of the arms were appropriate to the loads, and the entire assembly weighed just 11 oz (0.31 kg).

Test dummy

Test wheelchairs were loaded with a 190 lb (86 kg) anthropomorphic test dummy of the type used in automobile crash testing. Each wheelchair was tested with and without use of a lap belt to restrain the dummy.

Test wheelchairs

Test wheelchairs were configured in the manner specified in ANSI/RESNA standard WC/01—Determination of static stability, with the lowest part of the leg support/footrest 50 mm (2.0 in.) above the test plane. Rear wheels were adjusted to their farthest rearward position. Forward and backward static stability was measured.

The following seven wheelchairs/configura-tions were tested:

Hospital—Solid: Hospital-style folding wheelchair with solid tires, 8" caster wheels.

Breezy—Solid: Quickie Breezy folding wheelchair with 7.5" solid casters.

Breezy—Pneumatic: Quickie Breezy folding wheelchair with 8" pneumatic casters.

Quickie 1—Solid: Quickie 1 rigid wheelchair with 5" solid casters.

Quickie 1—Pneumatic: Quickie 1 rigid wheelchair with 6" pneumatic casters.

Whirlwind II: folding chair with 7" "Zimbabwe" T-section rubber caster wheels.

Omnidirectional: Prototype wheelchair using 8" omnidirectional front wheels.

Videotaping of test trials

Over 200 controlled test trials were run. The trials were videotaped to allow further analysis, including

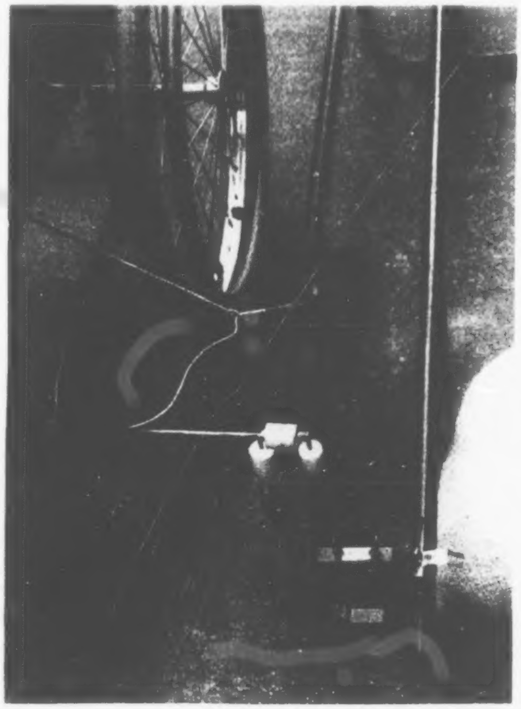

Figure 2. Wheelchair guide and speed measurement equipment.

Table 1. Results of testing seven different wheelchairs/configurations.

Wheelchair/ configuration	Wheelbase (inches)	Static Stability Angle (degrees) Backward	Static Stability Angle (degrees) Forward	Highest Obstacle Cleared (inches)* 3 mi/hr	Highest Obstacle Cleared (inches)* 6 mi/hr
Hospital—Solid	16	12°	19°	3/4	4/4
Breezy—Solid	17.5	13°	24°	4/4	5/4
Breezy—Pneum.	17.5	10°	24°	6/4	7/4
Quickie 1—Solid	17	10°	22°	3/4	4/4
Quickie 1—Pneum.	17	9°	24°	5/4	6/4
Whirlwind II	14	11°	18°	4/4	5/4
Omnidirectional	24.5	10°	38°	7/4	10/4

*Obstacle height increments = 1/4 in (6.4 mm). 3 mi/hr = 1.3 m/s, 6 mi/hr = 2.7 m/s.

slow motion viewing. **Figure 1** shows two refinements of the test setup: 1) a number flipchart for videotaping, that allows easy identification of test trials when scanning the videotape; and 2) visual markers on the dummy, wheelchair, and background wall, which would assist in making future kinematic analyses.

RESULTS

Test results are summarized in **Table 1**.

In the quantitative results (i.e. highest obstacle cleared) there were no differences between the dummy being belted versus not belted into the wheelchair seat, although we observed clear differences in how the wheelchair and dummy tipped and/or fell.

CONCLUSIONS

The test program was highly successful, producing useful relative measurements of forward dynamic stability. The test was repeatable, with consistent results. Tests of seven wheelchairs/configurations confirmed that the test can be used to reveal and quantify differences in forward dynamic stability between 1) different wheelchairs, 2) different rolling speeds upon impact with the obstacle, and 3) different types of caster wheels installed on the same wheelchair. Our test methods and specialized equipment could be re-created by other wheelchair test facilities at reasonable cost.

Since there was no difference in quantitative results between the dummy being belted versus not-belted into the wheelchair seat, the test might reasonably be simplified to employ an ANSI/RESNA (or ISO) standard-style dummy, secured to the wheelchair. This hypothesis should be tested.

In November 1995 we submitted draft language for a proposed new Part of ISO 7176—Wheelchairs, based upon this test, to the ISO Breakout Group on Wheelchairs—Part 2: Dynamic Stability.

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DETERMINATION OF STATIC STABILITY OF MANUAL PRONE CARTS

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ABSTRACT

Because commercially available prone carts have been found by SCI users to have several deficiencies, static stability evaluation of four (4) manual prone carts was performed according to the procedure outlined in ANSI/RESNA WC-01, 1990, to determine if static stability was a factor.

Two commercially available model were evaluated, the E&J and Gendron, as well two newly designed prone carts, the SCI PC 22 and the Sammy LS. The results indicated that the prone carts differed with respect to their overall tippiness due to their dimensions and overall height. The type of load, 75 or 100 kg with humans, was also a factor of significance. The study demonstrated that all four prone carts were quite resistant to tipping and that the angles at which they tipped were far beyond those expected in normal use.

BACKGROUND

Persons with spinal cord injuries are at high risk for developing pressure ulcers because of decreased mobility, sensory deficits and injuries due to transfers and other factors. Because SCI patients sit in wheelchairs for extended periods of time, the sacral and ischial areas are the most common sites for pressure ulcers.

The healing process takes several months. During that time, the SCI patient must lie on the side or in a prone position. Either of these positions precludes the use of a wheelchair. The prone cart provides a mechanism for mobility without jeopardizing the healing process.

PROBLEM STATEMENT

The prone cart provides a valuable alternative to prolonged bedrest; however, users have found the design of the commercially available: E&J and Gendron carts to have several deficiencies such as inadequate body support for comfort and safe positioning. These models are also difficult to use for maneuvering, braking and for completing activities of daily living (ADL).

RESEARCH QUESTION

The authors hypothesized that the deficiencies found by users on the commercially available prone carts may be related to their design and measurements. As a result the study to determine static stability was conducted.

L to R: SAMMY LS, E&J, Gendron & SCI-PC 22

METHOD

Testing equipment: A rectangular testing platform (120 x 160 cm) incorporated an electric motor that adjusted the inclination up to 30 degrees. A 4 cm wooden bar was used to chock the wheels in performing the static stability evaluation. A protractor was used to record the progression of the raised platform' angles.

Performing the test: For purpose of comparison between the prone carts, the two height adjustable models were set at their highest setting, E&J at 77 cm and Gendron at 80 cm off the floor. The other two prone carts were not height adjustable. The height of the SCI-PC 22 is set at 89 cm and the SAMMY LS is set at 85 cm off the floor.

Static tipping angle rearwards, forwards and sidewards was performed with two able-bodied individuals of 100 and 75 kg respectively. Finally, the tipping angle was measured when a piece of paper could pass under the un-chocked wheels without turning them.

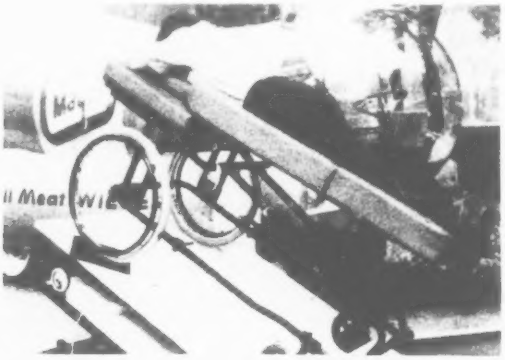
RESULTS

The static stability test results for each of the prone carts are presented in Table 1.

Table 1.

Static tipping angle rearwards in degrees	*Human subjects*	
	75 kg	100 kg
E&J cart	28°	28°
Gendron cart	28°	28°
Sammy LS	28°	25°
SCI prone cart-PC 22	29°	29°
Static tipping angle forwards in degrees		
E&J cart	28°	28°
Gendron cart	28°	28°
Sammy LS	29°	29°
SCI prone cart-PC 22	29°	29°
Static tipping angle sidewards in degrees		
E&J cart	21°	19°
Gendron cart	26°	21°
Sammy LS	18°	16°
SCI prone cart-PC 22	24°	22°

Sidewards evaluation with the Gendron



Forwards evaluation with the SCI-PC 22

DISCUSSION

The test for stability compared the performance of two commercially available manual prone carts, the E&J and Gendron, and two prone carts designed by the authors, the Sammy LS and the SCI-PC 22. The prone carts were tested at their highest height setting. The static tip angle was assessed for each prone cart under 6 different test configurations: Load type (75 kg and 100 kg) and Tip direction (Rearwards, Forwards, and Sideways). Since the intent was to distinguish differences in overall prone cart performance, a repeated measures ANOVA was applied to the data with the test configurations grouped by Load type. The prone carts (E&J, Gendron, Sammy LS, and SCI-PC 22) served as the repeated measures. There were no significant differences found in Load type, Prone cart type, or interactions. Given the relatively small data set used, however; the basic assumptions and requirements for an ANOVA procedure can be questioned.

The sample size was small and the distribution of the static tipping angles appeared not to support a parametric analysis; so a non-parametric statistical test was justified. The appropriate test for this condition is the Friedman two way layout (Hollander & Wolfe, 1973; Siegel, 1956). By considering the static tipping angles obtained for all 6 testing configurations for the four prone carts, an overall ranking of the "tippiness" of the prone carts was obtained.

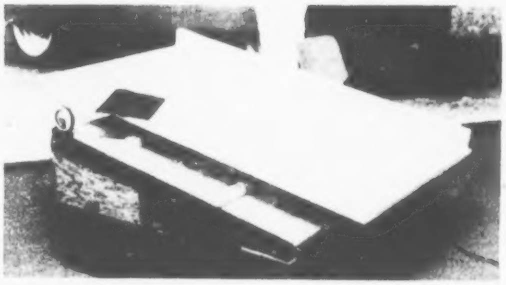
From most stable to least stable prone cart, the data indicate the following order:

SCI-PC 22, GENDRON, SAMMY LS, E&J

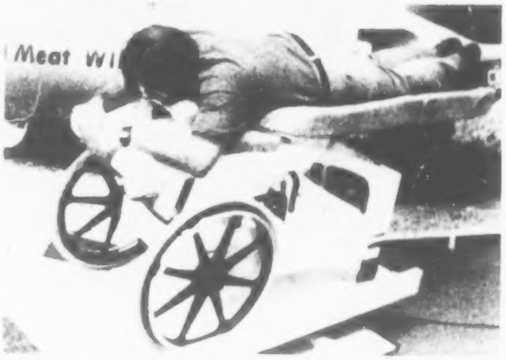
CONCLUSIONS

This study demonstrated that all four prone carts were quite resistant to tipping and that the angles at which they tipped (greater than 15°) were far beyond those expected in normal use (the angle of a ramp for wheelchairs is 4°).

Finally the authors have concluded that the deficiencies identified by SCI users regarding commercially available prone carts are related to other aspects of their design.



Testing platform



Sideward testing with the Sammy LS

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WHEN WHEELCHAIRS TIP BACKWARDS BEYOND THEIR STABILITY LIMITS

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ABSTRACT

Injuries due to rear-tipping accidents are common. In this study we tested the hypothesis that, with the wheels locked, the rear wheels rotate slowly backwards during a fall, whereas with the wheels unlocked, the rear wheels rotate quickly forwards. We videotaped 10 subjects in a wheelchair while they dropped from beyond their balance points onto a mat with the rear wheels locked (L), with two hands grasping the rear wheels (TH) and with the wheels unlocked (UL). There was no significant difference between the L and TH conditions. In both, the rear wheels moved and rotated backwards. In the UL condition the rear wheels moved and rotated forwards and the wheelchair fell more quickly, with mean differences from the L condition of 442 mm, 84.0° and 0.52 s ($\underline{p} < 0.0001$). A model to explain these differences was developed and validated. We conclude that, in the event of a rear-tipping accident, a wheelchair user should firmly grasp and pull on the rear wheels.

BACKGROUND

Wheelchair-related injuries are common and often serious (1). Although such injuries are multifactorial, stability is a factor in the majority of cases. Rear stability is the angle of a tilting platform from the horizontal at which the forces under the uphill wheels become zero (2). This value is significantly lower with the wheels locked than unlocked (3), primarily due to the different axes of rotation. However, there is no available literature regarding what happens to a wheelchair once the stability limit has been exceeded. Pilot work on this subject suggested that the differences induced by locking or grasping the wheels were substantial and that these differences might have major implications for the training of wheelchair users in how to fall safely.

RESEARCH QUESTION

We hypothesized that, with the wheels locked (either by the mechanical wheel locks or by the user firmly grasping the wheels), the rear wheels rotate slowly backwards during a fall, whereas with the wheels unlocked, the rear wheels rotate quickly forwards.

METHODS

We studied 10 nondisabled volunteers in a single representative rear-wheel-drive, manually propelled wheelchair. With a 30-cm-thick foam pad behind the wheelchair, we tipped the occupied wheelchair backwards to the point where the wheelchair was balanced over the rear wheel. When the subject was ready, the investigator allowed the wheelchair to fall backward. In a randomly balanced order, this procedure was followed under three conditions: the wheels-locked (L), two-hands grasping the wheels (TH) and wheels-unlocked (UL) conditions.

From the videorecordings we derived three measures: the horizontal displacement of the rear axles, the rotation of the rear wheels and the time for the fall to occur. Matched-pairs $\underline{t}$ tests were used to compare the conditions.

The results of the empirical testing suggested a model to explain the observed differences. To evaluate the assumptions and implications of this model, we conducted brief experiments with variations in friction and rolling resistance.

RESULTS

The horizontal displacements of the rear axles are shown in Figure 1. In addition, the L and TH conditions both resulted in a rearward rotation of the rear wheels, by mean values of 43.7 and 46.8° respectively; there was no significant difference between these two conditions. The UL condition resulted in a forward rotation of the rear wheels by a mean value of 40.3°. The mean differences between the UL condition and the L and TH conditions were 84.0 and 87.1° respectively ($p < 0.0001$ for both).

In the L and TH conditions, the wheelchairs took a similar length of time to fall, with mean values of 1.20 and 1.12 s respectively; there was no significant difference between these two conditions. The UL condition resulted in faster fall, with a mean value of 0.67 s. The mean differences between the UL condition and the L and TH conditions were 0.52 ($p < 0.0001$) and 0.45 s ($p = 0.0001$) respectively.

In the model-validation experiments, with the wheels locked, when wedges were placed behind the rear wheels, the drop to the ground was prevented. With the wheels unlocked, when wedges were placed in front of the rear wheels, the rear wheels were prevented from rolling forward and they remained stationary during the drop. With one wheel locked and one unlocked, the locked wheel rotated backwards and the unlocked wheel forward such that the wheelchair came to rest on the floor at an angle of 45° to its initial orientation.

DISCUSSION

The hypothesis was corroborated. With the wheels locked, the rear wheels rotate slowly backwards during a fall, whereas with the wheels unlocked, the rear wheels rotate quickly forwards. The extent of these differences were highly significant, both clinically and statistically.

The finding that rear tipping was prevented when wedges were placed behind the locked rear wheels has implications for static-stability testing, providing support for the recommendation of Cooper et al. (3) that no barriers should be placed downhill to the rear wheels when rear stability is measured with the wheels locked. With the wheels unlocked, wedges in front of the rear wheels prevented the "submarining" effect of the rear wheels rolling forward as the wheelchair dropped. This has implications for stability testing, suggesting that wedges should be placed uphill to the rear wheels when rear stability is measured with the wheels unlocked.

The major implication of this study relates to the training of wheelchair users in the safest course of action in the event of a rear-tipping accident. The natural reaction when tipping backwards is to turn and reach out in the direction of the fall to fend off obstacles, to avert the fall or to provide a measure of shock absorption. The disadvantage of this method is that the user can injure the upper extremity, no minor issue for a person who may need the upper limbs to propel the wheelchair and to transfer. If a user does reach out with one hand, the results of this study suggest that he or she should pull firmly on the wheel with the other hand to slow and guide the fall. Because we found that a significant yaw will occur when only one wheel is locked, if there is a preferred direction in which to turn (e.g., away from danger or toward a safer landing area), the hand chosen to grasp the wheel should be the one on the side away from the direction in which one would prefer to turn.

The results of our study suggest that it might be preferable for the user to use both hands to grasp and pull on the rear wheels as forcefully as possible, flexing the neck and trunk as well. (If the legs are flaccid and there is a risk of the knees striking the user in the face, then a thigh strap should make it unnecessary to use the hands to block the thighs.) Grasping and pulling on the wheels with both hands would have a wheel-locking effect (slowing the fall and lowering the forces on impact). Also, as we found in pilot work, some subjects are able to avert the fall altogether. The user may be able to further decrease the forces on impact to the extent that the flexor muscles of the arms, neck and trunk are able to act as shock absorbers. If there is an injury to be incurred, it is probably better to sustain a stretch injury to the muscles than an impact injury to the head.

Further clinical studies on such falling strategies are clearly needed. Even so, on the basis of this study, we suggest that users who find themselves beyond the rear-stability limits should firmly grasp and pull on the rear wheels.

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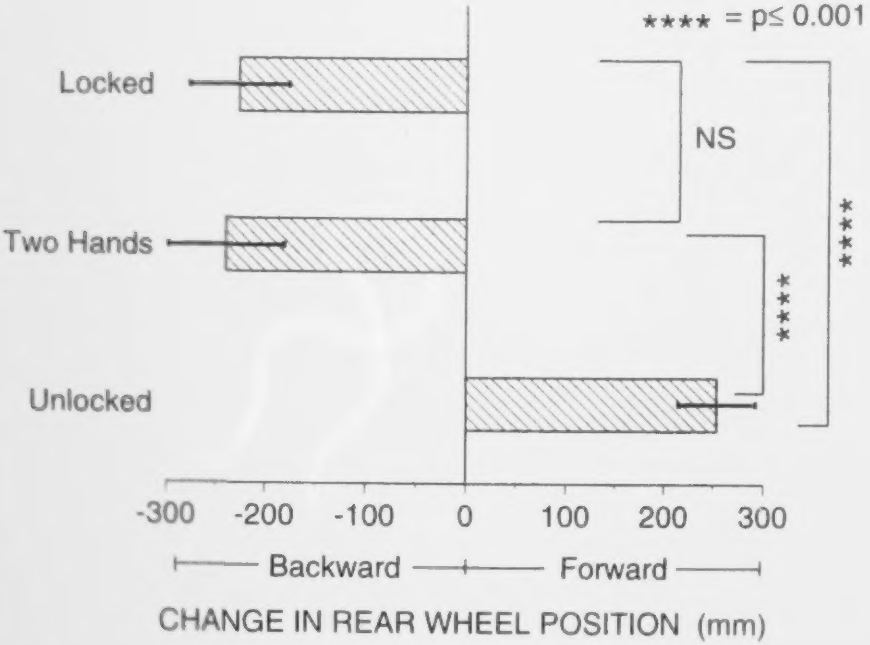

Figure 1: Horizontial displacement of rear wheel (mm).

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CRUTCH - LIKE TRANSFER BLOCK

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ABSTRACT

This paper describes the design and development of a pair of crutch-like transfer blocks. A totally different design concept from the typical simple transfer blocks was adopted. The crutch-like transfer blocks are adjustable in height and provide forearm support for people transferring themselves in and out of a wheelchair. Details are provided so that the crutch-like transfer blocks can be duplicated.

BACKGROUND

Patients that are confined to a wheelchair must often move themselves from a chair to an adjacent surface such as a bed. This movement is sometimes difficult due to body morphology. If a patient has short arms or long trunk, transfers from one surface to another is impossible without the use of a transfer block. A transfer block is a device which allows the patient to elevate the body high enough above the surface on which he is seated so that he can then shift his body to an adjacent surface.

The problem with the transfer blocks commercially available is that they lack vertical adjustability and forearm support. Patients using these devices may have different arm lengths. A set of transfer blocks that could be adjusted up or down could be thus used by a wide range of patients. A second problem with the typical transfer blocks available is the vulnerable position of the wrist during use. While performing a transfer, the weight is supported by the two hands as the body is elevated. The simple transfer blocks being used do not offer any support for the forearm or the wrist should the blocks become unstable during the maneuver. The purpose of this project was to design and construct a set of transfer blocks that are vertically adjustable in length and provide some degree of forearm support.

STATEMENT OF THE PROBLEM

A pair of height adjustable transfer blocks that provide forearm support are needed to be used by patients to transfer themselves in and out of a wheelchair. This device should satisfy the following requirements:

1. It should be safe. Safety is identified as the most important characteristic of the device because of the physical limitations of the target population.
2. It should be easily adjustable and comfortable to use.
3. It should be affordable.
4. It should be easily built. The device should have as few parts as possible to fasten together. The individual parts would also need to be easily machined.
5. The weight of the transfer blocks should be kept to a minimum. The transferring maneuver involves the patient manipulating the transfer block with one hand. Since this task is often repeated several times a day, the weight of the block must be kept to a minimum such that this does not overly fatigue the patient.
6. The strength and durability of the transfer block must be kept to a maximum.

RATIONALE

The crutch-like transfer blocks were developed because commercially available transfer blocks lack vertical adjustability and forearm support.

DESIGN & DEVELOPMENT

Several designs were considered starting with a simple commercially available transfer block. The original idea was to modify the simple transfer block by adding a leather support strap that wraps around the wrist and additional blocks under the base to allow adjustability in height. However, the addition of blocks to attain a certain height is inconvenient at best. Also, the leather support strap needs to be pulled tight with the teeth and/or requires the assistance of a helper. Another approach that was considered to adjust the height was to include a handle that is capable of sliding up or down steel support tubing. However, none of these modifications promised significant improvement over the existing transfer block. It was thus decided to try a radical departure from the basic shape of a transfer block. The outcome of this route was the development of the crutch-like transfer block shown in Figure 1. Six characteristics including safety, cost, ease of construction, material acquisition, ease of operation and weight were identified as evaluation criteria to compare the new transfer block with the original simple design and slightly modified redesigns. The Pugh method (1) was used to select the optimal redesign.

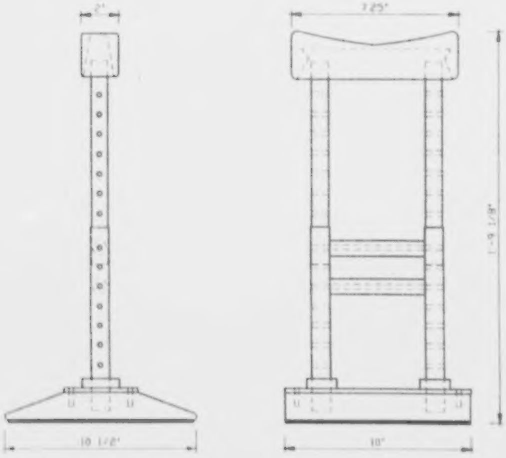

Figure 1. Crutch - like transfer block.

The main parts of the crutch-like transfer block are the base, a base plate, support posts, an axillary support and a handle. The base of the transfer block is constructed of oak. The angled shape of the base allows it to be slid slightly under the patients leg during the transfer movement. The top, flat portion of the base has two 7/8" holes in diameter drilled in it to accept the steel tubing. A non-slip base covering is attached to the bottom of the base. A steel plate that covers the flat top portion of the base, provides support for the steel tubing. This plate is attached to the base with eight wood screws. The plate has two steel collars welded to its surface through which the steel tubing passes. The steel tubing is silver brazed to the collars for support and firm anchoring. Two different diameters of steel tubing are used as support posts. The posts, which are inserted into the base, are 7/8" in diameter and 10" in length and penetrate one inch into the base. The posts used for telescoping axillary support are 3/4" in diameter and 11" in length. The axillary support is also constructed from oak. It has two holes drilled into it to accept the telescoping posts. The axillary support is covered with a rubber cushion similar to those found on commercially available crutches. The handle is constructed of a wooden dowel 4" in length and 3/4" in diameter. It has a 13/32" hole drilled through its longitudinal axis to accept a 3/8" 16 UNC SAE grade 8 steel bolt. This bolt passes through the tubing and handle to secure the handle in place. Wooden knobs were used to secure the bolts to the handles which are covered with commercially available handle pads.

The major concern for the telescoping tubing was buckling. A 1020 DOM steel tubing with a yield strength of 60 kpsi was selected for the telescoping tubing. This allowed for a factor of safety of 2 against buckling when a compressive load of 400 lbs is applied to one transfer block. The factor of safety was calculated using the secant column formula. Also, stress analysis was performed on the handle. The wooden doll part of the handle was neglected in this analysis, and it was assumed that the load is carried only by the steel bolt. The 3/8" 16 UNC SAE grade 8 steel bolt was found to sustain a point load of 400 lbs applied at its mid point with a factor of safety of 2.

EVALUATION

The transfer block prototypes were evaluated by the staff at Lake Park Rehabilitation. Three staff physical therapists, two aides, and one physical therapy assistant participated in the evaluation process. Each of the evaluator was asked to use a rating system from 1 to 10, with 10 being excellent, to evaluate the prototype in each of the following categories: adjustability, ease of use, weight, sturdiness of construction, safety, stability and durability.

The overall evaluation indicates that the prototype transfer blocks provided adjustability, ease of use, sturdiness of construction, safety, stability and durability. The staff indicated that the weight of the prototype transfer blocks was their only concern. In order to reduce the weight of the transfer blocks, it is suggested to replace the wooden base with a plastic or composite base. Also, and in order to provide a better non-slip surface for the bottom of the base, it is suggested to use a rubber base instead of the non-slip base covering that was utilized. The final cost of the pair of transfer block prototypes was about $250.00.

DISCUSSION

A pair of height adjustable transfer blocks have been designed and built to provide forearm support for people transferring themselves in and out of a wheelchair. The crutch-like design represents a totally different design concept from the typical simple transfer blocks which lack vertical adjustability and do not offer any support for the forearm or the wrist should the blocks become unstable during usage.

The population identified as being most likely to benefit from this transfer block design has the following characteristics: a) temporarily or permanently confined to a wheelchair, b) have an arm length to trunk length ratio at an unacceptable range to allow buttocks clearance during transfers, c) possess sufficient upper body strength to elevate and support their body weight on their arms, d) have adequate balance and body awareness to perform the transfer maneuver, e) have adequate mental capabilities to understand the use and/or adjustment of the transfer blocks.

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LIFT ASSIST DEVICE

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ABSTRACT

This paper describes the design and development of a device to assist a patient out of a wheelchair who is physically unable to come to standing under his own power. The design of this lift assist device incorporates a seat with a hydraulic jack mounted underneath it. The substitute seat can be easily fixed to a standard wheelchair via a hinge. The jack provides the input needed to tilt the seat to in order to assist the patient to raise from a seated position on his own. A footpedal is used by the wheelchair occupant to pump the jack. Details are provided so that the lift assist device can be duplicated.

BACKGROUND

Patients who are able to ambulate short distances are often not able to come to standing from a seated position under their own power when using a wheelchair. Because of their weak quadriceps muscles, they can't come to a standing position without physical assistance. With the use of a lift assist device, they can be raised from a seated position in the wheelchair to a position from which they can come to full standing and ambulate with a walker without the physical assistance of another person.

STATEMENT OF THE PROBLEM

A patient requires a lift assist device to help him to come to standing under his own power when using a wheelchair. This device should satisfy the following three basic requirements:

1. it should assist the wheelchair user to come to standing using his own power from a seated position without compromising safety so that the user can be as independent as possible;

2. it should be compact, easy to store and portable so that it can be easily installed into the wheelchair.

3. it should be affordable to those who do not have adequate coverage to supply them with expensive equipment;

RATIONALE

The lift assist device was designed and constructed because a similar and affordable device was not commercially available to the patient.

DESIGN & DEVELOPMENT

The proposed design incorporates a mechanical seat in which an input will assist the patient to come to standing out of a wheelchair. Due to the size and style deviation of various wheelchairs, this project was limited to develop a device that retrofits only RIDE-LITE 9000 series wheelchairs manufactured by INVACARE Corporation. Several design concepts were proposed in order to provide the input force including using a hydraulic jack, a spring and damper mechanism, and an airbag. The design that utilizes a hydraulic jack was found to be the most effective in satisfying the design requirements.

The design concept that was thus used incorporates a hydraulic jack to provide the force required to tilt the seat from horizontal to a 45 degrees angle. The jack is mounted under a substitute seat that is fixed to the wheelchair via a hinge. The wheelchair occupant uses a foot pedal to pump the jack. A cushion is placed on top of the seat for comfort. The prototype retrofitted to a wheelchair is shown in Figure 1.

The prototype of this lift assist unit includes five main parts:

1) seat, seat frame and seat subframe,
2) jack,
3) jack to seat and jack to chair connections,
4) jack input foot pedal,
5) lateral stabilizers.

Before retrofitting the unit to the wheelchair, the original cloth seat was removed to make room for the lift assist unit.

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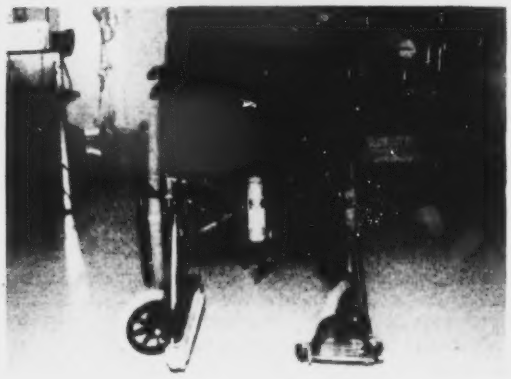

Figure 1. Lift assist unit retrofitted to a wheelchair

The seat, seat frame and seat subframe component is shown in Figure 2. The seat is made of plywood. The seat subframe is designed to fit into the standard seat mounting brackets of the wheelchair. Due to the resulting forces of the upward jack and the downward patient weight, very little force is needed to fix the subframe to the chair. Therefore, the subframe is attached to the wheelchair frame using industrial plastic ties. The subframe is fixed to the seat frame via a 1 foot long hinge. The seat frame is constructed of 1 in. wide by 0.25 in. thick steel bar stock.

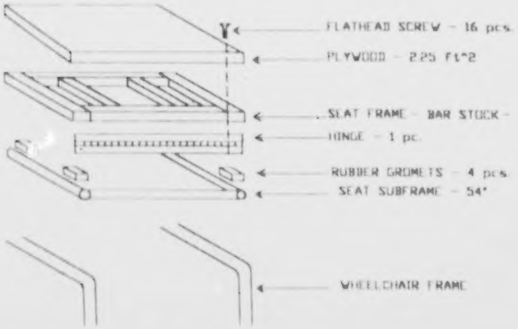

Figure 2. Seat, seat frame and seat subframe component

The jack to seat and jack to chair connections are shown in Figure 3. The jack is a 4 ton hydraulic bottle jack. The jack to seat connection consists of an axle (bearing rod) welded to the top of the jack screw extension with two shielded ball bearings attached at each end of the axle. The bearings have an outside diameter of 1.625 in., an inside diameter of 0.75 in., and a width of 0.5 in. As the jack raises, the bearings ride in grooves that are part of the seat frame. Two 1.5 in. by 0.25 in. pieces of steel angle stock are used to provide a base for the jack. The angle stocks are fixed to the chair via U-bolts.

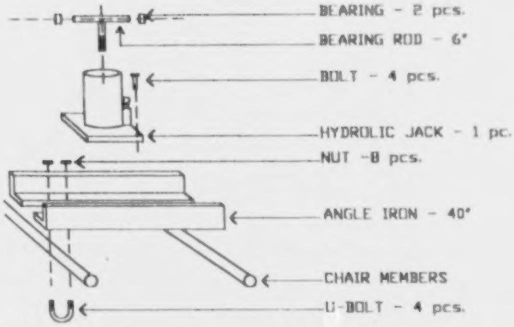

Figure 3. Jack to seat and jack to chair connections

The jack input consists of a foot pedal and a steel extension tube. The input device allows the user to raise the seat by flexing and extending the hip. The foot pedal includes a cloth strap that allows the user to pump the jack with their foot. The input device is attached to the jack by sliding the steel extension tube into the standard jack sleeve. It takes approximately 20 vertical repetitions to raise the seat to the desired 45 degree angle.

In order to prevent side to side movement during operation after installing the lift assist unit, lateral stabilizers were added to the wheelchair. These stabilizers replace the lateral stabilizing unit attached to the original cloth seat which is removed before installing the lift assist unit. These stabilizers are constructed using 0.125 in. braided steel cable and standard conduit fasteners. Total expenses for materials and supplies were $300.

EVALUATION

As designed the system is limited to retrofit only RIDE-LITE 9000 series wheelchairs. Experience to this date indicates that the goal of this project has

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been accomplished. When the device was tested, it was found that a patient is able to be raised from a seated position to a position at which he/she can continue to come to standing with minimal effort as shown in Figure 4.

DISCUSSION

An assistive device that improves the quality of life of a patient using wheelchairs has been developed and tested. This patient is unable to come to standing from a seated position under his own power, but once up he is able to ambulate short distances. The evaluation has been conducted using the criterion for the assessment of Assistive Technology (AT) (1). These criterion require AT services to be functional, simple, easy to use, acceptable in appearance, affordable, and to provide independence.

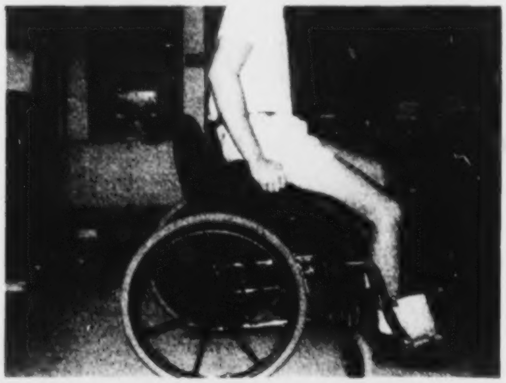

Figure 4. Lift assist unit being evaluated

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A DYNAMIC SOLUTION TO SEATING CLIENTS WITH FLUCTUATING TONE

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ABSTRACT

Seating clients with multiple disabilities can be an ongoing challenge. Many clients have a primary diagnosis and one or more secondary diagnoses. Each diagnosis brings an additional set of complications into the whole seating picture. These clients require continuous follow up as well as a good working knowledge of their disabilities and the posturing patterns associated with each one. This article will follow a client who has had several modifications made to his seating system as the clinical team learned more about him through progress.

BACKGROUND

The client's primary diagnosis is profound MR. He also has Spastic Athetosis, ATNR, and a strong startle reflex. All of these conditions lead to fluctuating tone throughout his body. When startled or excited he often exhibits severe extensor tone. At other times he will take on the "fencing" posture typical of ATNR and sometimes he will completely relax. His athetoid movements vary according to the stimuli in his environment. A positive effect of all this movement is good range of motion in most of his extremities with good orthopedic condition and body symmetry. The client's original Gunnell seating system was not meeting his current seating needs. Consequently, a custom contoured seating system with a 85° seat to back angle was prescribed and mounted to his existing mobility base. The system also had various additional positioning devices. This was done to give him maximum contact on his body to quiet his spasticity and inhibit some of his abnormal tone. Safety was also a concern because the client's high tone coupled with the spasticity have caused him to injure himself on different pieces of equipment. This approach proved unsuccessful. The client was not held in the closed seat to back angle as he leveraged off of the footrests, tilted his pelvis under his seat belt, and compressed the foam on the front of his cushion to reach full extension. It was also nearly impossible for caregivers to transfer him and then get his hips flexed and all the way back in the seat. Finally, the client seemed to extend because he was not comfortable. He could not tolerate the position for long periods of time without tonal problems.

OBJECTIVE

Follow up visits to make changes to the system and monitor the client's progress lead the clinical team to develop an alternative solution to his positioning needs. It was decided that a custom design with a dynamic component would improve the client's tolerance in his seating system and control his fluctuating tone. The new system would need to include a seat cushion that moved when the client went into extension and was able to pivot independently of the other positioning components.

METHOD / APPROACH

The dynamic design needed to perform the following. It would open to 120° when fully extended and then return to the preferred 85° seat-to-back angle once the client relaxed. The back support would remain static because it provided the greatest amount of upper support and stability while the client was in the seating system. Since the seat would be articulating the shear created was a crucial element that needed to be addressed in this seating system. A Jay seat cushion with a solid wood base mounted to the seat to back interfaces was used. The Jay Gel allows the client to go in and out of extension and to float back into the contoured back with a very limited amount of shear. To further reduce the amount of shear a pair of Whitmyer Seat-to-Back interface brackets were modified bringing the pivot point of the seating system closer to the pivot of the hips. This also provided the articulation. The dynamic component is a gas cylinder (200 N) that was added and attached to the bottom of the seat and the mobility base. The client, upon extension, is allowed to open his seat-to-back angle. The resistance of the gas cylinder then brings the seat cushion back to its original 85° The gas cylinder, designed for an automobile hatchback, was purchased at a local

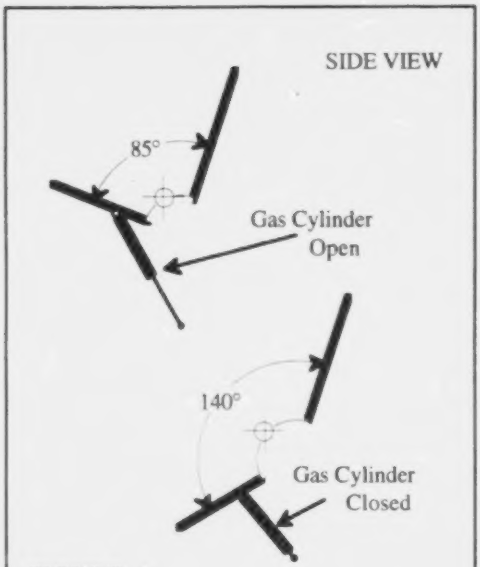

FIGURE 1

auto parts store. Stops attached on the lower brackets of the seating interface allow the seat base to have a 55° of excursion in the seat-to-back angle. (see figures 1 & 2)

RESULTS

Over the past several months the clients fluctuating tone has calmed significantly. Because of the systems ability to move with him the amount of time he remains in an extended position has decreased. his overall tolerance has improved and his ability to remain in the seating system has increased. Transfers are now easier for his caregivers because he does not resist going into his wheelchair. With this system and ancillary positioning devices he has become less abusive to himself. (see figure 3)

DISCUSSION

Clients with multiple disabilities often provide us a unique learning opportunity to explore many seating options and configurations. By taking time to explore various options instead of admitting defeat we have the ability to bring new solutions and ideas to light. Clinical teams are armed with a broader arsenal of seating options. The benefit to clients in larger populations can never be understated.

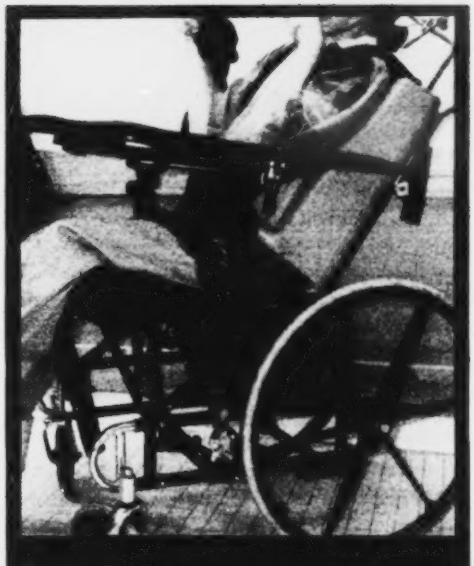

FIGURE 2

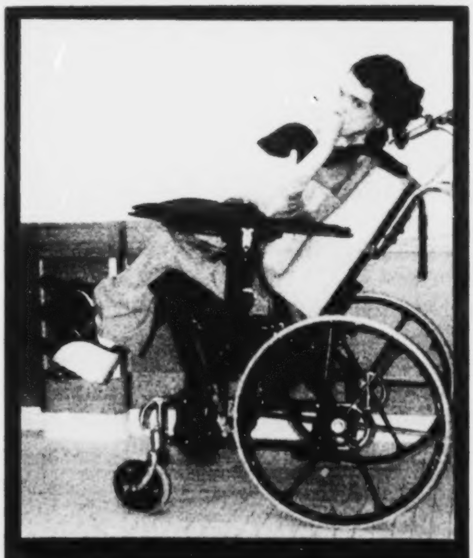

FIGURE 3

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A TWO POSITION SEAT TO BACK INTERFACE

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ABSTRACT

Many clients with severe extensor tone are difficult to position correctly in a seating system. Clients who cannot control their tone often stand in their wheelchairs or have little contact on posterior seating surfaces when in extension. In addition to these seating challenges, the clinical team must consider the caregiver who is responsible for transferring and positioning the client in the seating system. A client who is in full extension is difficult to transfer and cannot be positioned correctly until they relax or something inhibits their tone. The following article will describe a seat-to-back interface that allows ease of transfers and inhibits the extreme extensor tone exhibited by the client.

BACKGROUND

The client is a twenty-six year old female diagnosed with profound MR who resides in a state hospital. She exhibits high extensor tone that is mostly behavioral. At this time the client has a slight scoliosis and is prone to additional orthopedic problems such as extension contractures in all four extremities. Another area of concern is pressure on the back of her knees and head as these are often her only areas of contact with the chair when she extends. The final issue is that of safety. The client uses transportation for field trips from the facility and is not secure in her current seating system in this "standing" position. (see figure 1).

OBJECTIVE

The clinical team decided that the client would benefit from a new seating system mounted on the existing mobility base. During the mat evaluation the team found that the client would not extend when her hips were flexed to hold her at a 90° seat to back angle. This was done by seating the client with her lower legs hanging off the edge of the mat table with one team member holding her hips and one pushing from the back to the desired angle of flexion. To reproduce this effect a custom seat-to-back interface was designed. The design needed to interface the seat and back so that the angle would open for transfers to 130° and then close to 90° to control the client's tone.

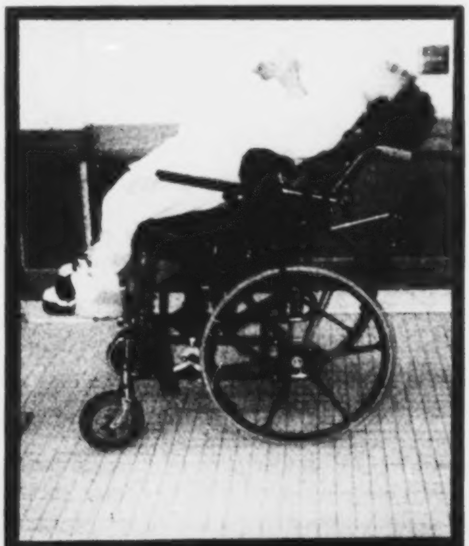

FIGURE 1

METHOD / APPROACH

The approach decided upon by the clinical team was achieved by modifying a pair Whitmyer Seat-to-Back interface brackets (see figure 2). This was accomplished by welding a stop on the lower brackets attached to the seat insert to prevent the seat-to-back angle from exceeding 130°. Because most conventional reclining wheelchairs have a considerable amount of shear, a pivot point four inches above the seat base and four inches anterior to the rear of the back insert was established. This geometry would help decrease the shear by bringing the pivot point of the seating system closer to the pivot of the hips. The client is placed into the chair at the

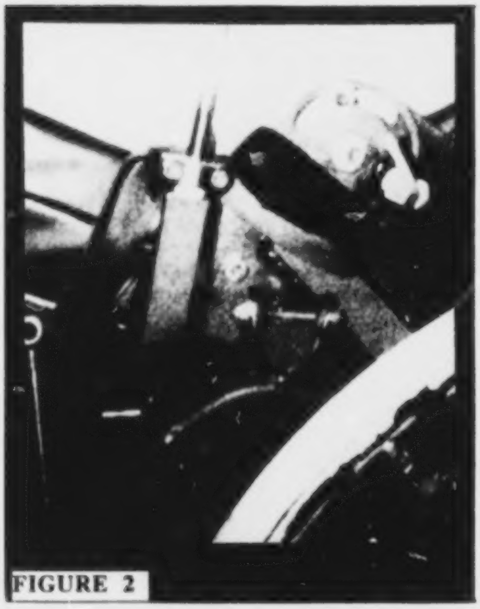

FIGURE 2

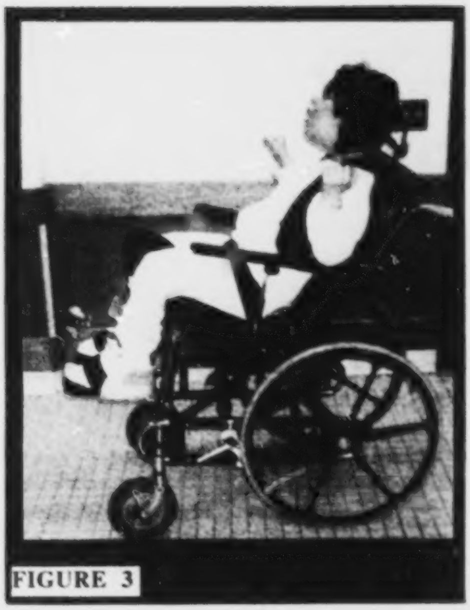

FIGURE 3

opened seat-to-back angle. Then after the hips are positioned properly and secured, the attendant goes to the back of the chair and brings the back forward in the anterior plane by the push handle until it locks into place at 90° (see figure 3). The locks are activated by a pair of spring loaded indexing plungers which are attached to the seat interface brackets .

RESULTS

The custom seat-to-back interface used in conjunction with correct seating has proven to be an effective approach to solving the client's seating challenges. The facility staff was inserviced on how to use the mechanism and position the client properly. Transfers have become easier and the client does not extend once the interface is locked. The client seems much more comfortable now that she is secure and safety is no longer an issue. (see figure 3)

DISCUSSION

The articulating recline mechanism is an excellent way to ensure that clients are positioned in optimal seat-to-back angles. This is important in institutional settings where a staff turnover rate can pose a problem in communication of the proper application of rehab technologies.. This makes inservice and training simpler and helps insure the proper positioning of clients

ACKNOWLEDGMENTS

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Design of An Ultrasound Soft Tissue Characterization System for the Computer-Aided Seating System

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ABSTRACT:

This paper describes the development of an ultrasound system for a Computer-Aided Seating System (CASS). Interface pressures and soft tissue thickness are measured over a 3 by 3 square sub array of support elements in the CASS. One pressure sensor and four ultrasound transducers are mounted in a swiveling head on the top of selected support elements. There are 36 ultrasound channelsin all. Under control of an 80486 DOS compatible personal computer, the ultrasound system scans the square area at 278 Hz repeat frequency and 7.5 MHz emitting center frequency. Results from pilot experiments showed that the longitudinal resolution is 0.2 mm and the range of depth measurement is from 0.5 mm to 5 mm. Fat and muscle soft tissue layers are distinguishable and their thickness can be measured separately. The system will be used to study in vivo tissue distortion in response to external loading, that is, to investigate the relationship between resulting internal distortion and the applied external pressure on the weight-bearing human buttocks in seating.

Key word: Ultrasound, Transducer, Thickness, Soft tissue.

BACKGROUND

Development of pressure sores is a serious clinical problem for persons with spinal cord injuries (SCI) and other people with mobility impairments and/or insensate skin. The etiology of pressure ulcers is yet uncertain. However, excessive pressures and tissue distortions are accepted as interrelated factors leading to the areas of cellular necrosis of tissue such as skin, fat and muscle that characterize pressure ulcers. The interface pressure between a seated individual's buttocks and seat support are primarily governed by the unloaded shape of the human buttocks, the support surface shape, the biomechanical properties of the buttocks soft tissues including skin, fat and muscle, the structural and material properties of the cushion such as stiffness, thickness and density and the body weight distribution on the cushion. Interface pressure is commonly used as an indication of the effectiveness of a seat support surface's ability to distribute body weight. However, interface pressure is difficult to measure accurately making its use as a method for comparison suspect. Also, high pressure alone is not a direct cause of vascular ischemia and tissue breakdown. Interrelated factors contributing to pressure ulcer formation are tissue distortion and localized, excessive uniaxial and shear pressure. Tissue distortion or strain is a better indicator of potentially damaging forces.

Ultrasound, as a non-invasive measuring technique, has the capability of determining changes of the soft tissue and characterizing mechanical properties of soft tissues in vivo. Ultrasound pulse-echo techniques have been frequently used to study the morphological and pathological state of tissues using a variety of acoustic parameters such as propagation velocity, impedance, attenuation, scattering, B/A nonlinear parameter of ultrasound, etc.

It is well known that the mechanical properties of soft tissues, such as elasticity, viscosity and mechanical impedance, depend on the condition of the tissues, for instance disease and age. Hence, these mechanical properties may give useful information in medical diagnosis. For example, the formation of pressure ulcers are related to unrelieved pressure, that closes tiny blood vessels and blocks the supply of oxygen and nutrients into tissue.

The ultrasound system attempts to measure the thickness of fat and muscle separately to quantify the deformation of each soft tissue layer quantitatively. Our analysis will compare the morphology of tissues and the elasticity of tissue layers with external loading. The analysis will try to help explain the phenomena of how deformation affects the physiology property of blood flow. Analyses and studies will show the behavior of soft tissue in load-bearing roles as they apply to the etiology of pressure sores.

SYSTEM DESIGN AND DESCRIPTION

A system block diagram of the ultrasound subsystem is shown in Fig.1. It consists of a 3 by 3 square array of support elements, 36 emitting/receiving channels, an amplifier, 36 signal processing channels, a DAS-1801HC high performance analog and digital I/O Board and an 80486 DOS compatible personal computer.

A pressure sensor (Foxboro Model:1860-02G-KDN-B) is fixed in the center of a swiveling head on the top each support elements and four ultrasound transducers (Etalon Model: PFM-754.75-SC2) are distributed around the pressure sensor (as shown in

Fig.2). The center frequency of the Ultrasound transducer is 7.5 MHz with focal zone of 0.44 cm to 5.2 cm. The width of frequency band is more than 60%, ring down time is less than 0.8 μs at - 20 dB with 1KΩ damping and less than 1.2 μs at -40dB with 1KΩ. The impedance tuned at cable end is 28 Ω +/- 5 and 0 degrees +/- 15°.

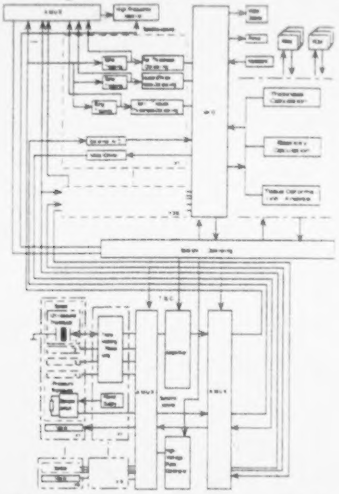

Fig.1 The Block Diagram of ultrasound Subsystem

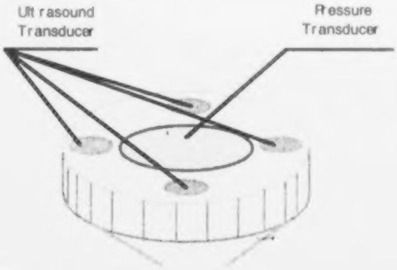

Fig.2 The Structure of Swiveling Head

When acquiring pressure signals, the computer sends a 10.008 Hz synchronizing clock signal to trigger a High-voltage Pulse Generator. The Generator gives a high-voltage stimulating pulse to the ultrasound transducer to emit a short-duration stress wave into human buttocks soft tissue. When the pulse meets the interface between fat and muscle or between soft tissue and bone, the energy is reflected backwards. When the reflected pulse reaches the sensor, the transducer generates a voltage. The pulse travels at constant velocity through soft tissue, the time delay between emitting pulse and receiving echoes is proportional to the thickness of the soft tissue. A oscillograph is used to monitor the process. The ultrasound system scans 36 ultrasound transducers in the square area with 278 Hz repetition rate. The repetition rate is low enough to allow each transducer to scan a maximum depth of 7.5 cm.

To obtain the thickness of soft tissue exactly, a pulse gate is set up on the display. The rising edge of the gate is aligned with the emitting trace and the falling edge of the gate is aligned with the reflecting echo trace. So, the width of the pulse gate is proportional to the thickness of soft tissue. Using this method, several gates can be set to estimate the thickness of different soft tissue layers such as fat or muscle simultaneously. Integration of the pulse gate results in a voltage proportional to tissue thickness.

When propagating in soft tissue, an ultrasound wave is attenuated because it is absorbed, reflected, diffracted, refracted and scattered by body soft tissue. The ultrasonic attenuation of soft tissues is 1dB/cm MHz. To compensate for this attenuation, a Time-Gain Control (TGC) scheme has been implemented. For this application, the TGC Rate is 1.155 dB/μs for the emitting center frequency of 7.5 MHz.

A DOS-1801HC High Performance Analog and Digital I/O Board is used to sample these voltage signals and convert them to digital representations. The signals are further processed and combined with pressure data and probes' position data in the computer, For example, the thickness and elasticity of soft tissue are calculated. The distribution of soft tissues' deformation and their response to the change of external loading are available to be quantitatively analyzed.

In addition, there are a number of acoustic parameters that can be used to study the pathological and morphological states of tissue. These are propagation, velocity, attenuation and absorption, internal scattering, reflectivity, and acoustic impedance. For example, one possibility is the collection of the attenuation content of ultrasound by comparing the corresponding content of the attenuated and unattenuated pulses. Different tissue layers have different attenuation coefficients. This parameter may be altered for damaged soft tissues.

LABORATORY TESTING & CURRENT STATE OF DEVELOPMENT

A. The Identification of Soft Tissues.

A one-channel prototype of the ultrasound system has been constructed and tested to determine its ability to detect the interface between skin and fat, fat and muscle and muscle and bone. Fresh pork and lamb were tested in vetro and human tissue was tested in vivo. The results have indicated that each of these interfaces can be detected. Fig.3 (a) shows that maximum amplitude of echo of lamb bone that is located 19.45 mm under the skin is 0.7 volts. The parameter that is measured is shown at the top of the figure while parameters at the bottom of the figure

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show the scale of the measurement. Fig. 3 (a) shows the thicknesses of different tissues. Here, the width of the pulse gate of CH 2 represents the thickness of fat and the first muscle. The measured width corresponds to propagation time in the first soft tissue layer of 10.09 μs. This corresponds to thickness of 7.6 mm. The width of pulse gate of CH 3 represent the thickness of the second muscle. Fig. 2 (b) shows separately a case of human leg in vivo. The width of the pulse gate of CH2 represents the thickness of fat. Here, the echo shows three basic characteristics:

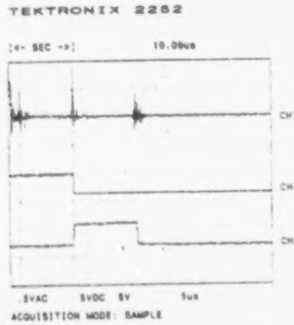

Fig.3. (a) The ultrasound echoes of lamb soft tissue (in vetro)

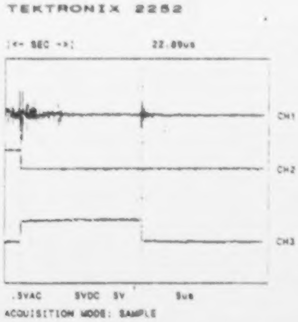

Fig.3.(b) The ultrasound echoes of human leg (in vivo)

1. The echo of skin interface, fat/ muscle interface and muscle/bone interface are greatly larger than the echo of soft tissues.
2. After external pressure is exerted to a threshold limit value, the thickness change of fat is greatly less than that of muscle.
3. The back scatter of fat is different from the back scatter of muscle. That is, there are more space echoes in fat.

These characteristics may not only help to identify interface echoes and adjust the pulse gate to track these characteristic echo signals but also may provide a scientific basis for a computer algorithm to detect echoes from the interface and automatically calculate the thickness of fat and muscle. At the same time, the computer analyze ultrasound back scatter signals to aid in the identification of soft tissues.

B. The Resolution Of The System

The longitudinal resolution of the system is an important parameter. In theory, the longitudinal resolution of the system is primarily dependent on the resolution of the transducer. Here, the Q of transducer is less than 1.67. Therefore, the longitudinal resolution is theoretically better than $AR=Q\lambda/4=1.67\times0.2/4=0.0835$. However, the actual resolution is worse. A simple measurement device consists of 7 copper wires whose diameters are 0.12 mm. The distance between each is less than 0.2 mm. The result of the test is shown in Fig. 4. The time between the first echo and second echo is 0.27 μs. Here, The ultrasound speed is 1480 m/s in water, so, the longitudinal resolution of the system is less than 0.2 mm when emitting at a center frequency of 5 MHz.

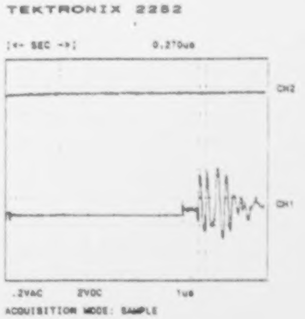

Fig.4 (b). The resolution of System

C. The Development of A New Structure Swiveling Head

The sensor is the key component of the new CASS. Here, the Ultrasound transducer is limited by the original swiveling head at size. Its diameter must be less than 0.2 inches. However, it must have a high sensitivity, wide band, good dampening characteristics and impedance characteristic including sound impedance matching and electric impedance matching. An initial prototype ultrasound transducer has been developed by the Etalon Inc. for this application

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THE DEVELOPMENT OF AC MOTOR DRIVE IN POWER WHEELCHAIR

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ABSTRACT

The analysis of the motor drive feeding an induction motor for a vector controller for an electric wheelchair system is presented. The new design of motor drive incorporates two inverter techniques, Pulse-width Modulation inverter and Voltage source Inverter, using a dead-time generator and Insulated gate bipolar transistor. The dead-time generator produces a time-delay for switching signals to prevent short circuit in the direct current link. However, the time-delay causes significant voltage-waveform distortion. The effects of the distortion are a reduction in efficiency and momentary loss of control. Distortions in the voltage-waveform are investigated through simulation as a function of time-delay, carrier ratio, and modulation index. Optimal values that minimize the distortion are selected.

BACKGROUND and INTRODUCTION

Approximately 1.2 million Americans and millions more around the world depend on wheelchairs as their primary source of mobility [1].

Even though most commercially available powered wheelchairs use permanent magnet direct current motors, induction motor is used in this research because recent advances in power semiconductor and microprocessor technologies have resulted in dramatic improvements in alternating current (AC) motor controllers in terms of reliability and efficiency (2). The role of the motor drive in the wheelchair system is the conversion of stored energy in the batteries to electrical power.

There are three major parameters, carrier ratio, modulation index, and time-delay, to consider in the motor drive. As AC powered wheelchair is a specialized application, there is a need for designing a suitable motor drive with optimized values for the parameters. Depending on the combination of the parameters, harmonic and waveform distortions can be significant or negligible. The effects of the significant distortions are a reduction in the efficiency and a momentary loss of control. The momentary loss of control makes a motor vibrate and/or causes noise. Fig. 1a and Fig. 1b represent the results of poor combination of the parameters. The waveform of Fig. 1a is the example of momentary loss of control because of an unexpected transition from positive pulse to negative pulse train. Fig. 1b shows a reduction of efficiency in the fundamental harmonic because a large portion of energy of input voltage is distributed into the subharmonics. Such cases need to be avoided in the wheelchair applicatin.

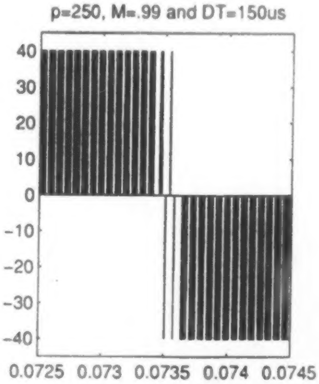

Figure 1a Examples of Momentary Loss of Conrol

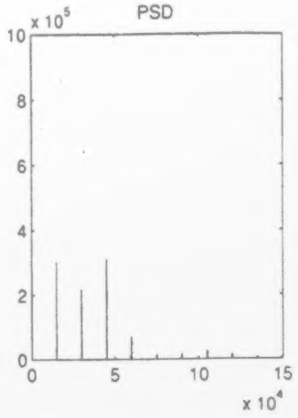

Figure 1b Example of Reduction of Efficiency

Theory of Operation of PWM-VSI

An inverter is a major component in the motor drive. An inverter circuit is used to transform DC power to AC power. For the wheelchair application, the source of DC power is a battery. In many inverter applications, it is desirable to obtain an AC output voltage with variable frequency and amplitude. There are three types of self-commutation inverters: current source inverter (CSI), voltage source inverter

(VSI), and pulse-width modulation (PWM) inverter (3). PWM inverter requires more complex control circuitry and faster switching components than CSI and VSI (3,4) For an induction motor, PWM inverter is commonly used with CSI or VSI. PWM-CSI is applied with a low switching frequency e.g., < 200 Hz, to minimize switching losses and PWM-VSI is typically used in a high switching frequency region with fast switching transistor (5). PWM-VSI technique is presented in this study because our switching frequency is much higher than 200 Hz to avoid an audible noise.

PWM-VSI switches state many times during a single cycle of the resulting output voltage. This rapid switching means that PWM VSI requires faster components than PWM-CSI (5). PWM-VSI needs high-power and high-frequency component such as Insulated Gate Bipolar Transistor (IGBT) (3). The frequency of VSI can be easily varied by varying the firing rate of the pulses supplied to the gates of IGBTs by the PWM. Adjustable frequency operation of a sine wave PWM-VSI for an induction motor controller requires the generation of three phase sine wave reference voltage of adjustable amplitude and frequency.

Insulated Gate Bipolar Transistor (IGBT)

IGBTs are used in this induction motor drive to switch current on and off. The inverter circuit is very important because the characteristics of the inverter can be used to decide the limit of switching frequency and time-delay.

The device is essentially equivalent to the combination of a metal-oxide semiconductor field-effect transistor (MOSFET) and a bipolar junction transistor (BJT). IGBT is a recent development in power MOS technology. According to Mihalic (6), IGBT has the high input impedance and voltage-controlled characteristics of the power MOSFET. In addition, it has a low on-state voltage drop even though the turn-off time of an IGBT can be significantly greater than that of a power MOSFET (3).

IGBT is similar to the power BJT, except that it is controlled by the voltage applied to a gate rather than the current flowing into the base as in the power transistor. The impedance of the control gate is very high in an IGBT, so the amount of current flowing in the gate is extremely small.

Dead-Time

In the inverter, the finite turn-off time of the IGBTs may cause a short circuit of the DC link at the instant of switch over between the two elements connected in series across the DC link. Thus, it is necessary to insert a time delay in control signals to avoid the conduction overlap of the elements (7). However, the time-delay causes significant voltage-waveform distortion. The effects of the distortion are a reduction in the efficiency and a momentary loss of control when a long time-delay is used. If the turn-on speed is faster than the turn-off, the DC source will short.

METHODS

First, an investigation is made to clarify the relationships between the voltage-waveform distortion and the carrier ratio and modulation index of PWM. Further, the voltage-waveform in the inverter output is investigated with respect to time-delay. We compare the distortion qualitatively with several output waveforms and harmonics. Moreover, optimal values are selected that minimize the distortion for both fundamental and harmonic components of the voltage-waveform in the output of the motor drive for operating conditions representing three motor speeds.

RESULTS

Selecting Carrier Ratio

Frequency of triangular carrier signal was chosen to be 15 kHz. The switching time in a PWM inverter has a detrimental effect on inverter operation. Usually, a relatively high switching frequency is employed to obtain a near-sinusoidal output voltage and current. The reason that higher than 15 kHz was not selected because of IGBT switching time and time-delay.

Selecting Modulation Index

The modulation index is prefered to be higher than M=0.9, even though lower values of M can be used as frequency of reference signal becomes smaller. When the modulation index is low, low-order harmonics become comparable with the fundamental component that makes the output waveform significantly distorted. When higher modulation indexes are used, the resulting signal is more efficient.

Selecting Time-Delay

10 μs of time-delay was determined to be optimum to feed into an induction motor when low distortion and power loss in the signal and a short circuit of the DC link. If the time-delay is too small, then it is not enough to avoid a short circuit of the DC link and if the time-delay is too large, then a tiny pulse disappear from pulse train or appear in a wrong place and causes significant waveform distortion, especially when the carrier frequency is high.

CONCLUSION

An optimum voltage wave-form and its power spectrum density are shown in Fig 2a and 2b. Comparing Fig 1a and 1b with Fig 2a and 2b, Fig. 2 shows a clear wave-form and Fig. 2b has smaller sub-harmonics in the power spectrum density. Through the results of simulation, the optimal values chosen minimize the distortion of the voltage-waveform and achieve a high efficiency in the output of the motor drive for operating conditions for three motor speeds.

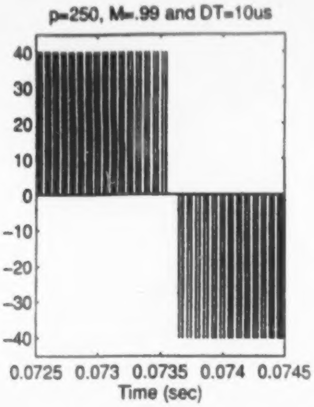

Figure 2a Resulting Voltage Wave-form

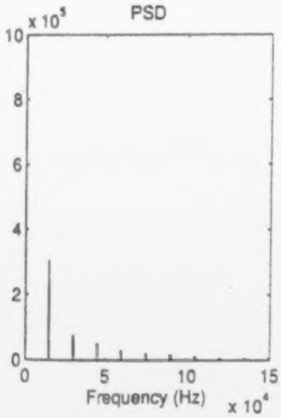

Figure 2b Resulting Power Spectrum Density

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ASSISTIVE TRUNK LOADING WHEELCHAIR LIFT

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ABSTRACT

Loading a wheelchair into the trunk of a car can be a truly arduous task. More often than not, the wheelchair being loaded is heavy and extremely cumbersome. This makes the loading of a wheelchair into the trunk of a car very difficult for many people, especially for disabled people themselves. This has created a need for a device that will assist in loading and unloading a wheelchair into and out of the trunk of a car. A need that has been satisfied with an assistive trunk loading wheelchair lift. A trailer hitch mounted device that through the use of a motorized winch loads and unloads a wheelchair. The device was designed, built, and tested for under $175.

BACKGROUND

Persons with disabilities which confine them to wheelchair are often assisted by friends or relatives when traveling. If the person aiding the impaired individual does not have the use of a specially equipped vehicle, difficulties may arise in loading and unloading the wheelchair. The wheelchair itself can be heavy as well as cumbersome, especially when loading the chair into the trunk of a vehicle. Assistance may be required in the loading and unloading process. Wheelchair lifts are available to the public at costs ranging from $1,000 to $3,000 which, for the average consumer, is too expensive. Therefore an affordable alternative is needed.

PROBLEM STATEMENT

The decided task is to design, build, and test a mechanism that will assist a disabled person with limited mobility or an individual of limited strength in loading and unloading a wheelchair into and out of the trunk of an automobile. This device should not require a permanent modification to the trunk or the wheelchair. Changing of the structure of the wheelchair or car such that it can not be returned to its original condition without remanufacturing would be impractical and expensive. The device should also be compact, durable, and easily operated by individuals with limited strength and ability.

RATIONAL

In deciding on a design for the wheelchair lift, several constraints were considered. The first of these which was cost. The device would need to be inexpensive in order to make it cost effective for the average person. A $250 cost limit was chosen. Meeting the budget requirements in part called for a simple yet durable design which would be easy to manufacture. Another consideration was making the device universal. It had to be able to be used with any vehicle that had a trunk with enough room to store and transport a wheelchair. This in turn would keep costs down by reducing the amount of time needed to develop individual designs for specific vehicles. If the lift were to be a motor assisted mechanism, it would be limited to the power provided by a 12 volt automotive battery. The lift should also allow the user access to objects normally stored in the trunk, such as the spare tire and jack.

When considering the user of the lift, it was assumed that a person using the device would be able to lift 25 pounds with a minimal amount of difficulty. The user should not, however, be required to do any excessive lifting. They should also be able to load or unload the chair in a minimal amount of time so as not to expose them to foul weather for a long duration. As for the safety and convenience of the user, it was decided that the device meet the applicable codes and regulations set by the Americans with Disabilities Act and the Occupational Safety and Health Act (OSHA)

DEVELOPMENT

In making the lift universal to all vehicles, a trailer hitch mounted mechanism was decided upon onto attach the lift to the vehicle. A two part frame for the mechanism was designed so that it would insert into a class three "Draw-Tite" style hitch. The frame was designed as a two piece structure, constructed of 2 inch square steel tubing

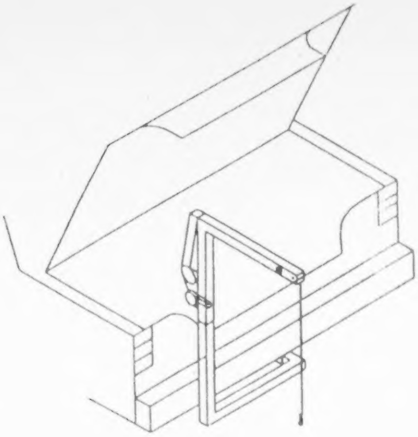

Figure1. Assistive Wheelchair Lift

of 3/32 inch thickness. The device could be disassembled and put in the trunk with the wheelchair when not in use. Although a smaller size of tubing could be used safely, the larger tubing gave a visual sense of security. When a person sees a structure that is made of members which are small in proportion the size of the mechanism, the small members appear visually to be weak. Therefore a larger size member will appear stronger. The corners of the frame were given extra support with 3 inch gussets.

A stress analysis of the frame was conducted using the average measured weight of a standard wheelchair, 40 lb., in order to check for safety in the mechanism. Three critical points were determined. The most critical of which was on the 1 inch pin at the pivot point of the frame. The bending moment was calculated followed by the stress due to bending at that point. Finally the factor of safety was determined to be 3.4 using

$$n = \frac{S_y}{\sigma}$$

where S_y is the yield strength, n is the factor of safety, and σ is the stress due to bending. (Shingley and Mischke, 1989)

The lifting mechanism could have been a hand-cranked or motor driven winch. Because of the time required to lift the wheelchair with the hand winch, a motor driven winch was more feasible. In regard to weight considerations however a 1500lb capacity winch was too cumbersome to use. A winch had to be designed for lifting small loads in a short amount of time. To accomplish this a small electric motor was combined with a hand winch, Figure 2.

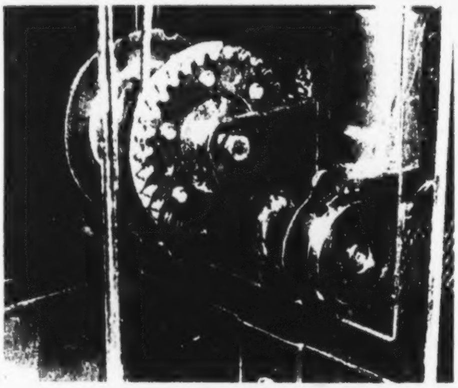

Figure 2. Specially Designed Winch

A specially designed shaft/coupling replaced the original shaft in the motor. This coupling enabled the winch to be directly driven. The motor was then bolted to the winch via a custom made sheath and the winch was bolted to the upper piece of the frame. A 1/4 inch coated cable was run from the winch through the frame to the end of the boom The end of which is attached to the wheelchair.

DESIGN

The lift is a two piece trailer hitch mounted device The bottom piece extends approximately 3 inches past the end of the hitch. Then the frame angles 90 degrees to the left and reaches 26 inches from the center of the car parallel to the ground. This was done so the user would not need to maneuver the wheelchair around the device while guiding it into and out of the trunk. From here the frame turns upward and rises 23 inches to a pivot point. A 1 inch diameter steel pin is used as the pivot. This is also the separation point for the top and bottom sections. Taking the device apart allows for easy storage when it is not in use, as well as, reducing the weight of each piece that must be put in the trunk.

The top piece is an L shaped boom that slides down on top of the pivot pin with the winch and motor attached opposite to the boom. The top piece extends upward another 23 inches where it then angles 90 degrees and continues out 26 inches. The motor direction is controlled by a directional switch on the boom.

To operate the lift, the user slides the bottom section into the trailer hitch and inserts the locking pin. The user then joins the top section to the bottom. Placing his/her left hand on the boom so that their thumb is over the control switch and depresses the switch in the down direction to let out the cable. Once the cable is out, attach the clip hook to the folded wheelchair. The hook is attached to a metal ring that is clamped to the frame of the chair at the approximate center of gravity. The user then presses the switch in the up position lifting the chair off the ground. When it is raised up, the chair will want to swing so that it is parallel to the ground. Placing the right hand on the locked wheel will control the motion. As the horizontal chair clears the edge of the trunk, using the left hand, the user swings the boom over the trunk and presses the down switch. While the chair lowers, the user guides it into the trunk with his/her right hand which is still on the locked wheel. After the wheelchair is in the trunk, the cable is detached and rewound. The lift is then disassembled and placed in the trunk with the wheelchair. Total time for the procedure is around 75 seconds. Removing the chair from the trunk follows the same steps in reverse.

RESULTS

The assistive wheelchair lift has been designed, built, tested, and demonstrated. The final design for the lift costs approximately $150. Well below the $250 limit. If the lift were to be manufactured the production cost would decrease. The mechanism was developed and constructed in about 25 hours. After numerous uses in testing and demonstration, it has had no difficulties with operation.

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ACKNOWLEDGMENTS

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USING AN LB301/LB201 LONG RANGE LASER DISPLACEMENT SENSOR FOR SHAPE-SENSING OF A BLACK RUBBER MOULDING BEAD BAG

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ABSTRACT

The LB301/LB201 laser displacement sensor produces spurious displacement readings when it is used to scan a black rubber moulding bead bag. If each scan is post-processed with an appropriate low-pass digital filter, the resulting displacement values agree very well with that obtained using a mechanical tracer. The laser sensor can measure a moving moulding bag driven at a horizontal velocity of 20mm/sec with acceptable accuracy. At this velocity, it takes under 10 minutes to trace a 460mm x 460mm bead bag.

BACKGROUND

The LB301/LB201 laser displacement sensor has a range of ±100mm at a reference distance of 300mm. At this reference distance it has a light spot size of 1.2mm x 25mm. A previous study found that the sensor can measure contours of moving spherical objects ranging from a black rubber basket ball to a small blue rubber ball (28.4mm dia.) with acceptable accuracy for special seating. However, because the sensor measures displacement by sensing the angle between an incident and reflected beam, it was found that acceptable accuracy was obtained only within a subtended angle of about ±70° from the apex for spherical objects. (1)

OBJECTIVES

To measure the performance of the laser sensor in shape sensing of a black rubber moulding bead bag impressed with the contour of a thin adult.

METHOD

Determining safe working horizontal velocity (Fig. 1)
The LB301 sensor was mounted on the Z-axis (vertical-axis) of a vertical machine center (VMC). The visible emitted beam was aligned vertical to the table of the machine. The bead bag, with the impression of a ball (28.4mm dia.), was placed flat on the table which was driven to move under the sensor in the X-direction (horizontal) at pre-determined velocities. For each velocity, the sampling rate for the laser sensor output was adjusted to capture a sample per 0.2mm of displacement along the X-axis.

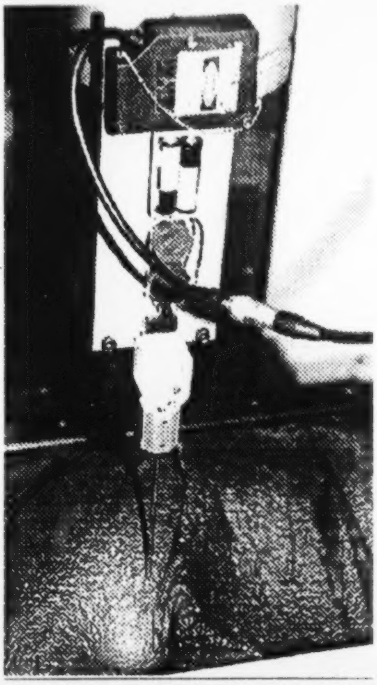
Fig. 1 Laser sensor, touch probe and bead bag

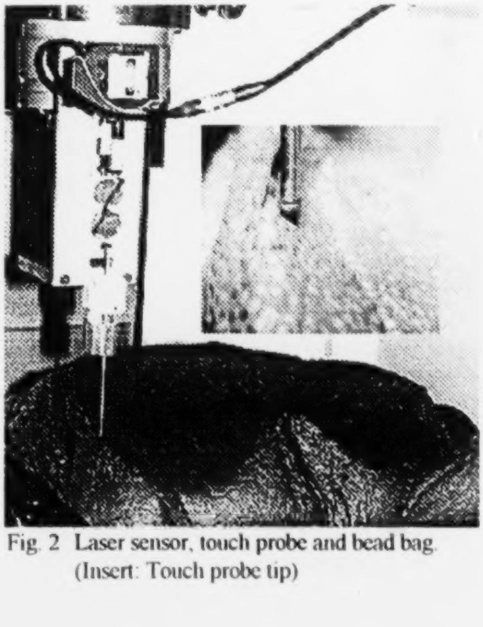
Fig. 2 Laser sensor, touch probe and bead bag. (Insert: Touch probe tip)

Verification of displacement measurements (Fig. 2)
The bead bag was impressed with the contour of the buttock of a thin adult. The bag was driven along the X-direction at a velocity of 20mm/sec. A scans was taken, across the ischio-tuberosites. Vertical displacement measurements were taken at intervals of 0.2mm of displacement along the X-axis. Vertical displacements were also sampled every 5mm of horizontal displacement using a touch probe, also mounted on the Z-axis. The probe had a 4 mm dia. steel ball at the tip

RESULTS

Safe working horizontal velocity (Fig. 3)
Essentially the same displacement values were obtained from a velocity of 120mm/min through 4,000mm/min. The displacement values for 6,000mm/min and 12,000mm/min were clearly off. To be cautious, a velocity of 1,200mm/min (i.e. 20mm/sec) was chosen for the remaining measurements in this project.

Verification of displacement measurements (Fig. 4-5)
Fig. 4 showed that, except for the rapid spurious displacements, the vertical displacements measured by the laser sensor corresponded well with that by the touch-probe. The spurious displacements varied too rapidly to be real from an anatomical view point. These were clearly an artefact from the sensor in response to the lumpy texture of the moulding bag. The beads inside the bag produced small but severe contours on the surface. As stated earlier, good accuracy was obtained from spherical objects within a subtended angle of about ±70° from the apex. If the output of the laser sensor was taken to be a low frequency signal contaminated with high frequency noise, the noise could be filtered out using a low-pass electrical filter. Fig. 4 showed that after processing by a digital 2-pole low-pass Butterworth filter, the resulting signal corresponded very well with that from the touch-probe.

DISCUSSION

From the results obtained, the laser sensor is suitable for shape-sensing of a black rubber moulding bead bag for special seating for two reasons. . At 20mm/sec, it requires only about 10 minutes to scan a 460mm x 460mm (approx. 18" x 18") bead bag if only cross-sections 20mm apart are traced. The displacement accuracy is quite acceptable if post-processing of the displacement values with a digital filter is performed.

Since the performance of the sensor is done empirically, it is prudent to use it with caution and check its results with known means when in doubt

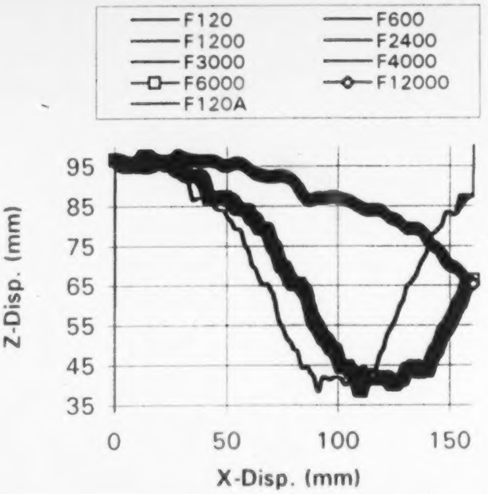

Fig. 3 Response of the laser sensor at different target velocities

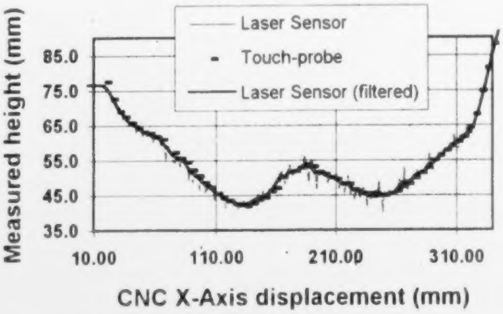

Fig 4 Displacement before and after filtering

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WHEELCHAIR TRANSPORT STANDARDS WHAT ARE THEY ALL ABOUT?

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Abstract

Two voluntary wheelchair transportation standards are under active development. One of these standards addresses the performance of the wheelchair tiedown and occupant restraint system (WTORS). The WTORS is being developed by a task group within the Society for Automotive Engineers(SAE). The second standard is being developed by the RESNA Subcommittee on Wheelchairs and Transportation (SOWHAT), and specifically addresses the additional requirements for wheelchairs marketed for use as an occupied seat in a motor vehicle. The focus of this paper is to present the rational for the standards, explain the engineering principles behind the test methods, and suggest the relevance of the standards and test results to wheelchair users and prescribers.

Introduction/Background

Over the past decade, various subcommittees within the Technical Guidelines Committee of RESNA have been developing voluntary performance standards for production wheelchairs. These are now embodied in a sixteen part series that have been sanctioned by the American National Standards Institute(ANSI). These standards are now available to manufacturers and others from the RESNA office[1]. The standards cover a wide range of measurement and test methods and information disclosure requirements that must be followed if a manufacturer wishes to claim compliance with the standards. Many manufacturers are now testing to the standards and disclosing information in a standardized manner that allows accurate comparison between products by users and prescribers. An excellenct reference manual on the application of the wheelchair standards has been prepared by Peter Axelson and Jean Minkel with support provided by the Paralyzed Veterans of America[2].

The significant impact of this fifteen year long effort is only now becoming evident. As manufacturers disclose the test results in their marketing literature in compliance with the standards, wheelchair users and prescribers are for the first time able to objectively compare the performance and dimensional features of competing products. This work on transport standards builds on this postive experience with production wheelchair standards.

Increasing numbers of people with disabilities use wheelchairs, i.e., traditional manual and powered wheelchairs, powered bases, scooters, strollers, etc., as a means of accessing public and private motor vehicles. For many, the ability to use their wheelchair while riding in a transport vehicle is the only feasible means of gaining access to education, work or recreational activities. Wheelchairs, both traditional and contemporary, were not originally designed to be used as seats in a transport vehicle. That is the wheels, seat and frame structures and battery containers were not engineered to withstand the high forces of a crash condition. Futhermore, most wheelchairs do not have designated attachment points for securement to the vehicle, and therefore securement, both in terms of strength and location on the frame, can often be haphazard and uncertain from a safety viewpoint. Therefore, most wheelchairs do not provide the occupant the same level of rider safety as that provided by a seat in a car, van, bus or train. However, the reality is that thousands of individuals are using wheelchairs on transportation vehicles on a daily basis. This creates a potential safety hazard for the wheelchair occupant, as well for other passengers in a transit vehicle in the event of a crash situation. These standards efforts are attempting to address this reality without impinging upon the independence or freedom of choice of wheechair users.

Use of the wheelchair as an occupied seat in a motor vehicle raises a new set of concerns from the safety perspective. That is, it now adds a set of additional performance requirements for which most wheelchairs were never originally designed. There are actually two complimentary factors that must be addressed simultaneously if a person is to be given a level of crash protection comparable to a person riding in a regular vehicle seat using shoulder and lap belt restraints. First, when used as a seat in a motor, the wheelchair should provide a level of crashworthiness equivalent to regular(OEM) vehicle seats. Secondly, the wheelchair occupant should have access to occupant restraints anchored in positions to cross the body at appropriate anatomical locations. And finally, the system, wheelchair, wheelchair securement and occupant restraint, must be tested to ensure that it provides occupant protection to some agreed upon standard level[3].

The devices that secure the wheelchair to the vehicle, termed tiedown devices, and the restaints that hold the occupant in the wheelchair during a crash event must also meet some recognized performance standard, as they do when installed in motor vehicles.

There are essentially two basic approaches to the securement of wheelchairs that are in common use today; attendant-operated and auto-docking devices. The attendant-operated type is reflected largely by three or four belt-type devices that hook to various parts of the wheelchair frame[3]. The second approach has been the use of docking-type securement devices. These are mechanical devices that have one part attached permanently on the wheelchair and the mating part located in the vehicle. Current devices have worked reasonably well for private vehicles, particularly in the driver station, but they have yet to be used widely in public transportation applications due to the absence of a universal method of attachment[4]. Other methods that are used, but discouraged from the safety perspective, are frame and wheel clamps[3]. In most cases these devices will not meet the crash protection levels proposed in the WTORS standard.

Voluntary standards, both national and international, are being developed for wheelchair tiedown and occupant restraint systems. These efforts, which began in the mid 80's, and will soon result in a voluntary national standard for wheelchair tiedowns and occupant restraint systems(WTORS) [6]. This standard is essentially identical to the standard being adopted by the International Standards Organization(ISO)[7]. Although these initial restraint and tiedown standards primarily address the dynamic performance testing of four-belt designs, they have established the precedence and forum for the next step, which is a standard for auto-docking securement devices. Compliance by the securement industry means that we will have a nationally recognized performance standard for securement of wheelchairs, and restraint of the wheelchair-seated occupant, while riding in a motor vehicle.

More recently, an ANSI/RESNA subcommittee, termed SOWHAT, has been working closely with ISO in the development of a compatible transport wheelchair standard. For the first time this work has brought together users, prescribers, manufacturers, restraint/tiedown manufacturers, researchers and representatives from the private and public transporters, and vehicle manufacturing industries. This effort has resulted in a draft standard for wheelchairs intended for use as a seat in a motor vehicle and is scheduled for completionin 1997. Results from testing many production wheelchairs already in the marketplace suggest that relatively few enhancements will be required to meet the requirements of the ANSI/ RESNA-SOWHAT standard.

Rational for Standards

Federal Motor Vehicle Safety Standards(FMVSS) guide the requirements for seat design and securement, as well as occupant restraint performance for all motor vehicles. These standards are based on many years of research based on barrier crashes of actual vehicles containing instrumented dummies called an Anthropometric Test Dummy(ATD). Based on statistical incidence of injury severity, most crash tests are designed to represent frontal impact, with rear, roll-over and side impacts being given a lower priority. Differentiation of federal requirements for tiedowns and occupant restraints is based on vehicle mass or in some cases number of passengers. The rational is that passengers in lighter weight vehicles such as cars, mini vans, or full sized vans up to 10,000 lbs GVW are more lightly to experience higher forces during a crash situation, than are people riding in heavier vehicles, such urban or over-the road buses or trains. Therefore one type of vehicle, those less than 10,000 lbs, by law requires occupant restraints and the other does not.

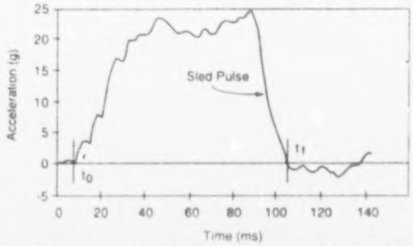
In every case the passenger seat is secured to the vehicle for the protection of the seated occupant, and for the protection of other passengers riding in the vehicle. For this reason the wheelchair should also be secured in a motor vehicle. The use of occupant restraints should apply equally to wheelchair occupants as it does to any other passenger on that size of vehicle.

Finally, vehicle seats are designed and tested to provide a known level of passenger protection which varies depending on the size of vehicle in which they are installed. Wheelchairs in turn, that are intended to be used as seats on motor vehicles, must meet some minimum requirement that will offer the rider an equivalent level of injury protection as would the OEM seat in the vehicle. The evolving standards are based on these goals and the associated test methods are based on the engineering biodynamics developed over many years of research by the automobile industry. Clearly, there must be compatibility between the two standards. In essence, the actual laboratory test procedure is the same for both standards.

Engineering Principles

In most vehicle crash situations there are two crashes events; the first involving the vehicle exterior and the second involving the occupants coming in contact with the interior of the vehicle. Seat design, vehicle interiors and occupant restraints, including air bags, are all designed to aid the occupant to "ride down" the secondary event thereby minimizing injuries. In lieu of prohibitively expensive full vehicle crashes, development of transport wheelchair standards employ a simulated vehicle crash. A laboratory impact sled on rails, carrying the secured test wheelchair or test securement device/occupant restraint, is first accelerated to a known velocity and then rapidly decelerated to simulate a barrier crash. High speed cameras record the event and velocities and decelerations are accurately determined using instrumentation mounted on the sled and ATD. This test procedure can be accurately repeated at a much lower cost then an actual barrier test.

Additional test parameters that must be standardized include the speed or velocity at impact, how quickly the test device will be stopped(decelerated), and what criteria will be used to determine pass or failure of the test. Again the tests rely heavily on the experiences gained and the practices used in automobile safety testing. Most frontal impact testing of vehicles under 10,000 lbs. GVW is at a velocity change of 30 mph at a rate(deceleration) that will cause the test sled to experience a deceleration of 20g(20g/ 30mph). A deceleration of 20 g produces a force equal to 20 times the mass of the object being decelerated. In order to insure that this standard is met the sled deceleration pulse must fall within the corridor defined by the diagram in Figure 1. It can be noted that acceleration to peak velocity and deceleration to zero all occurs within a time of about 105 ms. Crashes in larger vehicles may be simulated by using a 10g/30mph crash pulse, for example.



In addition to the impact sled test three additional laboratory tools are used. The wheelchair occupant is simulated by a 50 percentile male ATD which weighs 165 lbs (75kg). When testing the wheelchair tiedowns and occupant restraints, the ATD is placed in a representative wheelchair on the impact sled. The surrogate wheelchair is of rigid construction, designed to withstand repeated crashes and apply crash loads on the tiedowns and restraints equivalent to those of the average powered wheelchair. The rational being that not knowing what type of wheelchair will be secured by the tiedown device, one should test to a worst case situation, which is the powered wheelchair. When testing wheelchairs, a standard surrogate tiedown device is used which allows measurement of tiedown loads and repeatability from test to test.

Although ATDs can be used that measure the actual decelerations at various anatomical locations, these measures are not used in the WTORS and SOWHAT standards. What is used are displacement measurements derived from the high speed camera recordings taken during the crash event. In the testing of wheelchair tiedown and occupant restraints the overall goal is: 1) to prevent

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the wheelchair from impacting against the occupant, and 2) to prevent the occupant from impacting on the interior of the vehicle. Horizontal displacement limits have been set for both the wheelchair and the ATD, as identified by it's head and knee movement. Table 1 shows the maximum displacements used to determine pass/fail of a WTORS.

Table 1

Horizontal Excursion Limits (mm)			
Measurement Point	Excursion Variable	Pelvic Restraint* Only	Pelvic & Shoulder Restraint
Test Wheelchair	$ExWC_{peak}$	200	200
Dummy Knee	$Exknee_{peak}$	425	375
Dummy Head	$Exhead_{peak}$	950	650

* ISO standard only

A similar set of excursion limits exist for testing transportable wheelchairs in the SOWHAT standard. In addition, the wheelchair seat frame must also not impinge into the occupant space and must keep the ATD in the seated position after the test. For the safety of other passengers in the vehicle any wheelchair part with a mass greater than 100 gm(about 1/4 lb) must not become detached from the wheelchair. Also, a transport wheelchair must have identifiable locations on the frame for attachment of the belt-type securement devices and an occupant lap restraint.

Relevance to Users and Prescribers

It should be obvious that there are assumptions, arbitrariness and compromises made in the test procedures, and therefore limitations should be placed on the interpretation of the test results. First FMVSS tests have rather arbitrarily set 30 mph/20G as the test standard for motor vehicles. If you actually experience a velocity change greater or less than 30mph and experience a different deceleration pulse on impact, the forces imparted to your body will be different from those in the standard test. Also, the selection of the 50th percentile male ATD as the test standard for the WTORS test will not be representative of children, women or large males. At least in the SOWHAT test, four different sizes of ATDs are specified so the one appropriate for use in the wheelchair being tested can be used. A compromise has been made in the selection of surrogate test chair. It has been selected to represent an average of typical powered chairs. It does not represent manual chairs or heavier powered chairs. The displacements limits have been selected to represent typical interior space limitations for passenger movement in motor vehicles. If you are a driver sitting close to the steering wheel during a 30mph/20 G impact, you will most likely impact the steering column.

Conclusions

In summary, the test procedures are a standardized set of test conditions that can be readily reproduced in any qualified crash test facility around the world. Of importance is the fact that they represent only one actual test condition, that will be more representative of some crash situations than others. The main point is that there are recognized test standards to which wheelchair transportation products will be safety tested. And furthermore, users and precribers of these devices, through requesting test reports from manufacturers, can determine which products perform better than others.

The present work has been guided by the higher incidence severe frontal impacts, with emphsis on belt-type securement systems. Docking-type devices, although requiring very similar tests, present additional challenges from the standards development viewpoint. Also, side and rear impacts and roll overs are all realities of motor vehicles accidents. If equivalent options of travel safety are to be offered to wheelchair seated passengers and drivers, these challenging realities will also need to be addressed in future work.

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COMPUTER ASSISTED WHEELCHAIR PRESCRIPTION PROGRAM (CAWPS) SURVEY

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ABSTRACT

A computer assisted wheelchair prescription program could assist the provider with the wheelchair prescription process. To incorporate the needs, reservations, and experiences of wheelchair providers, a questionnaire was sent to RESNA Sig-09 members. Their answers were incorporated into the prescription program, and summarized below.

BACKGROUND

Keeping current with the growing list of wheeelchairs and prescription methodologies is a daunting task for clinicians and rehabilitation technology suppliers. An expert system for wheelchair recommendations is currently being developed, through the Department of Veteran Affairs (Project 4B485-DA), to assist prescribers with recommending mobility equipment.

The proposed computer program will assist in matching the mobility needs of persons with disabilities to a wheelchair which meets his/her specific requirements. The system will assist with the generation of the required follow up reports. The expert system will use information based on ANSI/RESNA wheelchair standards and input from leading experts in the field. The computer program will aid in the gathering of consistent relevant client data through the use of question prompts, help menus, and diagrams. Using the gathered data, the expert system will generate a prioritized list of wheelchair recommendations. The program may also be used to assist with staff training in the use of current wheelchair prescription methodologies. An initial prototype of this expert system is currently under development, and is undergoing assessment, Garand, S. A., & Shapcott, N (1995).

In an attempt to include the needs, requirements, and reservtions of wheeled mobility providers, a questionnaire was developed and sent to all RESNA Sig-09 members. 183 questionnaires were returned with the results following in this paper.

OBJECTIVE

This questionnaire was developed to determine potential users' requirements and perceptions of a computer assisted wheelchair program system. The questionnaire also sought information regarding potential users' computer experience and computer equipment. The collected information is being incorporated into the computer program.

METHODS

A questionnaire was developed and sent to RESNA Sig-09 members. The returned questionnaires were entered into a data base, and reviewed by the authors. The information was then compiled and incorporated into the computer assisted wheelchair program.

The questionnaire was separated into three parts: questions to help determine system requirements, questions to determine prescribers' prescription process and equipment resources, and questions to determine prescribers' experience with computers and access to computers. The survey consisted of yes/no, fill in the blank, and multiple choice questions.

RESULTS

183 individuals responded, identifying themselves as follows:

Clinician: 84
Rehabilitation Technology Suppliers: 63
Rehabilitation Engineers: 12
CPO/MD/RN: 6
Not Identified: 18

The respondents stated that their biggest wheelchair prescription problems are: 1) Client satisfaction is not quantified and used to improve their prescription process, and 2) Report generation and funding justification takes a significant amount of time. 50% of the respondents reported unquantified client satisfaction as a severe or very severe problem. 134/183 respondents reported that report generation and funding justification takes a significant amount of time as a severe or very severe problem.

The majority of respondents feel that they have current and comprehensive wheelchair information with a consistent and effective prescription process.

73% of the respondents do not have reservations about using a computer assisted wheelchair prescription system, and 90% of the respondents stated that their prescription process could benefit from an assistive computer program. Respondents who noted reservations stated that they are concerned with the system's ability to deal with customization issues, and the potential of removing the provider from problem solving, using a "cookbook approach" Other respondents stated that they lack computer equipment and/or experience.

Potential benefits of using a computer assisted wheelchair prescription program are: 1) easier data collection, follow up, and organization, 2) access to comprehensive data, and 3) the standardization of the prescription process.

The system does not need to include a computer, and the mean acceptable software cost is $500. 87% of the respondents would purchase a CD Rom to run the system. Windows is the preferrred operating system.

Respondents' computer experience and equipment varies widely. 44% of the respondents use Windows, 28% use DOS, 24% use MacIntosh, and 4% use Power Macs as their operating system. The majority of respondents who use personal computers use a 486, while MacIntosh users use the 6100, Powerbook, Quadra, or LC. 50% of the respondents have a RAM size of 4-8 MB, and another 20% have a RAM size of 8-16 MB. 66% of the respondents have access to a data line, 43% have access to the internet, and 37% have access to an on-line service.

The majority of respondents prescribe up to 20 wheelchairs per month with 71% of the prescribed wheelchairs being manual wheelchairs, 24% power wheelchairs, and 5% scooters. 80% of the respondents perform evaluations at more than one site.

Cerebral palsy and spinal cord injuries are the two most commonly encountered primary diagnoses.

The respondents use multiple devices to assist with their client evaluations. 63% have use of a seating simulator, while only 23% of the respondents use a pressure measurement device. 82% of the respondents have the ability to allow clients to try various mobility bases and wheelchair controls.

Providers learned about wheelchair prescription methodologies through courses and seminars (29%), other prescribers (22%), and journals (24%).

DISCUSSION

The respondents to the computer assisted wheelchair prescription program survey express that a software program would assist them with their evaluations and follow up documentation. Such a system needs to generate multiple recommendations and act as a supplement to their personal knowledge, not replace their skills and provide "cookbook solutions". The system needs to make the provider's prescription process more effecient by allowing for easier data collection, organization, follow up, and standardizing the prescription process.

If the proposed computer assisted wheelchair prescription program can achieve the above, respondents would be willing to purchase the software for approximately $500. The system should be portable and offered on Windows and MacIntosh operating systems.

The system could also be used to assist with the instruction of new staff, in conjunction with an experienced assistive technology provider. This software could provide a standardized methodology and instruction for wheelchair prescriptions.

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COMPUTER AIDED WHEELCHAIR PRESCRIPTION SYSTEM (CAWPS)

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ABSTRACT

Keeping up with the growing list of wheelchairs and current prescription methodologies is a daunting task for the individuals responsible for prescribing this equipment. A computer aided wheelchair prescription system (CAWPS) is under development. The proposed system will use a computer program to help match the mobility needs of people with disabilities to a wheelchair that meets their specific requirements and, assist with the generation of the required reports. The expert system will use information based on the recent ANSI/RESNA wheelchair standards and input from leading experts in the field. The computer program will aid in the gathering of consistent, relevant client data through the use of question prompts, help menus, and graphics. A prioritized list of wheelchair recommendations will be provided. A related program will also help train individuals in the use of current wheelchair prescription methodologies.

BACKGROUND

To date, the use of current literature and other information sources in helping therapists to develop an effective standard approach to match a client's needs with the most appropriate, currently available wheelchair has been limited by five major problems.

The first problem is, until recently, dimensional wheelchair data may not be measured similarly between manufacturers nor would a complete and standard set of objective information be available. Another problem is the rate at which new wheelchair types, accessories, and features are becoming available soon makes current knowledge obsolete. A third difficulty is developing a standard prescription process that can accommodate the wide range of possible client needs and also accommodate the ever increasing complexity of existing wheelchair features. Another difficulty is the cognitive overload placed on the therapist in trying to evaluate the complex relationship between existing wheelchair features and prioritized client goals. The final problem is the ever increasing amount of time spent on information retrieval and report generation required by the various agencies involved in the prescription process.

The ANSI/RESNA Wheelchair Standards Committee is working on the inconsistent wheelchair data problem by developing a set of standards to allow manufacturers to make available consistent and complete wheelchair information. Axelson et al. (1) published a guide to help explain how to use the ANSI/RESNA wheelchair standards in selecting an appropriate wheelchair. To help address the problem regarding the increasing rate of wheelchair features becoming available, Axelson (2) publishes an annual survey of light weight wheelchairs based on the ANSI/RESNA standards. Denison et al. (3) present a standard prescription process that focuses on providing the best possible manual wheelchair for an individual. Cognitive overloading and report generation time problems are being addressed for occupational therapy functional assessments by a computer program titled OT FACT (4). Another program titled FIESTAS (5) addresses funding information eligibility. These programs however, do not provide a specific tool for aiding in the prescription of wheelchairs. Two such prototype programs specifically targeted for wheelchair prescriptions were developed by Arnold et al. (6) and Hammel et al. (7). Both prescription software projects were abandoned and are not commercially available.

STATEMENT OF THE PROBLEM

Determining the most appropriate combination of current wheelchair features that best match user's goals in a cost effective and timely manner is becoming increasingly difficult, particularly amongst first time inexperienced wheelchair users. An expert system designed to aid a therapist or RTS in the prescription of wheelchairs appears to be the best solution to this problem. As of present, no such commercially available expert system was found.

RATIONALE

WHEELCHAIR EXPERT SYSTEM

In order to provide an aid to a therapist or RTS in the current wheelchair prescription process, a unique computer program is under development. Based on advice from leading experts in the field and a national survey (8), system goals were established and are given as follows.

The system must be easy to use in order to accommodate the wide variation in computer skills amongst therapists. The program must therefore run on both platforms the users are most familiar with, Macintosh and Windows. The program must have a graphical based intuitive means of operation and obtaining help. The system must be affordable to the users. In order to achieve this third party software with little or no run time or royalty fees must be used. The use of the program must decrease the time required for the prescription process by assisting in the preparation of written reports and justifications necessary to obtain funding. The software must also provide quick access to current, accurate, and standardized wheelchair information.

DESIGN

The basic expert system design is modeled after Denison's three step approach to wheelchair prescription. The first stage is to gather the necessary information to determine a client's goals. This includes proper fit, safety, personal preference, and activity goals. The goals are further categorized into primary, secondary and optional priorities. The second stage is to create an ideal model wheelchair that meets the individual's needs. Finally a rating is given to existing wheelchairs based on how well the device can meet the client's goals. The ratings are influenced or "weighted" by the priority of a given goal.

In addition constraints can be used to create a second rated list of wheelchairs. Possible constraints include, available funding, approved vendor lists, and local vendor support. The effect on clients' goals of both the original rated list and the constrained list of wheelchairs is presented. Information to aid in the preparation of written reports and justifications necessary to obtain funding is also provided. Digital video was used as one method to illustrate a broad concept of wheeled mobility. A diagram of the systems' functional blocks is given in Figure 1.

A graphical tool is also available to help the therapist "build" a typical day or days in the life of a client at work or school, week end, and vacation. Objects representing daily activities such as negotiating ramps, transferring in and out of a van, toileting, and performing pressure relief can be added to the screen thus providing a graphical representation of the clients' environment. Details about the environment such as the ramp angle can then be added.

After a question is answered the goals are effected which in turn modify a computer model of the ideal wheelchair. Any conflicts are identified and presented to the user for resolution. A graphical representation of the model is reflected by this modification. The effect any answer has on the ideal wheelchair can be seen on the screen as the answers are entered. This gives immediate feedback on the ramification any answer has on the ideal wheelchair.

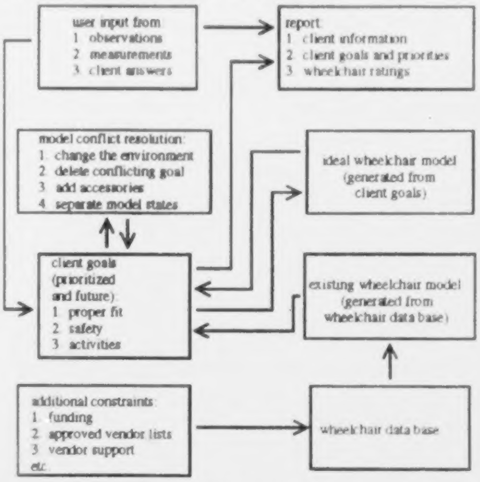
user input from
1 observations
2 measurements
3 client answers
report
1 client information
2 client goals and priorities
3 wheelchair ratings
model conflict resolution:
1 change the environment
2 delete conflicting goal
3 add accessories
4 separate model states
ideal wheelchair model (generated from client goals)
client goals (prioritized and future):
1 proper fit
2 safety
3 activities
existing wheelchair model (generated from wheelchair data base)
additional constraints:
1 funding
2 approved vendor lists
3 vendor support
etc.
wheelchair data base

Figure 1. CAWPS functional block diagram

Once all necessary questions are answered the ANSI/RESNA based wheelchair information and manufacturers' information is automatically rated in terms of meeting client goals. The wheelchairs can also be rated prior to this stage based on available answers, but the lack of a complete answer set will be noted in the report. The matching algorithm first translates wheelchair data base parameters to actual goal values. The difference between the actual goal values and the ideal goal values are used to generate a "relative level of matching" number from a predefined fuzzy surface. The fuzzy numbers are weighted by the clients' priority level to produce the number used to rate a wheelchair. The results of this complex process will be presented in an easy to understand graphical format.

DEVELOPMENT

The system requirements were defined through input from experts and results from a national survey. Based on these design requirements, software development tools were identified. The programming language chosen is C++, an object oriented language that facilitates a modular and easy to maintain design. The graphical user interface, data base interface, and rules based inference engine were purchased as cross platform C++ libraries. This approach allowed the development and testing of a single set of source code that can be easily ported to other platforms i.e. Windows, Macintosh and PowerPC. A program was developed to demonstrate the initial concept to our team of experts. Based on the feedback of this meeting a second user interface was developed to demonstrate the revised concept. To prove the feasibility of using the software libraries together, a small graphical expert system was developed which determined the wheelchair type required by an individual. The next stage is to develop a small scale working system to prove the design feasibility of generating an ideal model based on user input.

EVALUATION

The program can run on both platforms the users are most familiar with, Macintosh and Windows. The program has a graphical based intuitive means of operation and obtaining help. There are no run time fees and a low royalty cost for the inference engine library. Assistance in the preparation of written reports and justifications necessary to obtain funding is provided by the generation of a text file containing all pertinent information. This file can be loaded into most popular word processors for further customization. The proposed system should provide quick access to current, accurate, and standardized wheelchair information due to the system components chosen and the matching algorithm used.

DISCUSSION

The proposed CAWPS system should prove to be an effective easy to use, and affordable, wheelchair prescription aid to a therapist or RTS. A teaching aid program, based on a similar design but focusing on teaching wheelchair prescription methodologies, is also under development. The effectiveness of the expert system will be evaluated by September of 1996 followed by commercialization of the system in the following two years.

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SURVEYING SATISFACTION OF INTEGRATED CONTROLS USERS

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ABSTRACT

Twenty-four persons with severe physical disabilities participated in a telephone survey. The survey focused on their satisfaction with areas related to use of an integrated control device. The number of devices that the respondents could operate increased after procurement of the integrated control. The respondents were generally satisfied with their integrated control device. A moderate correlation coefficient was found between gadget appeal and satisfaction with devices. This sample was self-selected and voluntary. Therefore, additional studies in this area need to be conducted to substantiate these findings.

BACKGROUND

Assistive technology devices are now available that allow persons with severe physical disability to complete tasks that were impossible for them to perform only a few years ago. Users of assistive technology (AT) have an average of four devices (Angelo, 1992). In most cases two are high technology and two are low technology. When the user has severe physically limitations, it is advantageous to have one input device control all the output devices. Integrated controls allow users to operate power wheelchairs, augmentative communication device, computer, environmental control unit, and other devices that are controlled electronically.

The advantages of integrated controls are that persons with limited motor control can access several devices without assistance. The user does not need to learn a different operating system for each device. Using an integrated control, persons with physical disabilities do not have to wait for an able-bodied person to complete tasks or wait to have the input device positioned. They can control other output devices such as wheelchairs, communication aids, telephones, computers, televisions, window drapes, unlocking doors, and air conditioners at their will. This increases their level of independence, productivity, and provides more options for individuals who have minimal physical control. In addition, the operation of one control takes less valuable space within the users' reach. The disadvantages may include the need for additional training to understand how to operate the control. It may be difficult for users to remember which device they are currently controlling, and if the controller breaks, the whole system may become inoperable.

Integrated control devices are recommended for users when they have only one reliable access site and the optimum input device for each assistive device is the same. In addition, integrated control devices are recommended when the user prefers it for aesthetic, performance, or other subjective reasons.

Integrated controls technology has been commercially available for some time. However, information to guide and direct those most likely to benefit from integrated controls is grossly lacking (Guerette & Sumi, 1994). There is little information to guide consumers regarding the important features, to guide clinicians who are prescribing the devices as to what characteristics users should possess to make the match successful, or what features manufacturers should include as new models are developed. This leaves consumers, assistive technology practitioners (ATP), assistive technology suppliers (ATS), and manufacturers with limited knowledge as to how to proceed.

Reasons that additional information on integrated control is needed are two-fold. First, information in every aspect is limited. Consumers, ATPs, ATSs, and manufacturers operate on experience and intuition. Those inexperienced in dealing with integrated control have little information to guide. Improved information would benefit all.

Second information is needed as abandonment is a problem. More information will improve understanding what need to do be done to ensure successful with using integrated control and reduce abandonment.

METHOD

Sample

Twenty-four persons completed a telephone survey. The mean age was 34 years. The age range was 16 years to 59 years. Sixty-seven percent of the respondents had spinal cord injuries, 25% had cerebral palsy, 4% had multiple sclerosis, and 4% had head injuries. Seventy-nine percent were male and 21% female. Eighty-eight percent had no physical control over their body from the neck down and 12% had some control over their arms.

Procedures

A Likert type ranking scale and open-ended questions were used to collect data. Respondents were located through clinicians in North America at institutions who were known to recommend integrated controls. Clinicians indicated the number of clients for whom they had recommended integrated controls to the investigators. A corresponding number of pre-stuffed, stamped envelopes were mailed to each of the clinicians. The clinicians addressed and mailed the envelopes. The envelopes contained a cover letter explaining the project and a postcard. Persons choosing to participate wrote their name and telephone number on the postcard and mailed it. Once the postcards were received, the respondents were called and interviews were arranged at a convenient time.

RESULTS

Data were analyzed using descriptive statistics and correlation coefficients. Types of disability are reported in Figure 1. The range of years with a disability was from 6 to 39 years. The mean was 12.6 years.

The evaluation sessions ranged from less then one hour to more than six hours. The mean for an evaluation session was 5 hours and the median one hour. Forty-two percent had more than one evaluation session. Of those individuals who had more than one evaluation session, the range was from one week to more than two months. Fifty-eight percent felt they were included as team members during the evaluation and 42% indicated they did not feel they were team members.

The number of respondents who could operate specified devices increased after receiving an integrated control (Figure 2). Forty-two percent received all the pieces at one time and 58% received them sequentially.

Respondents were asked what training method and/or persons they found most helpful. The respondents indicated the following groupings as most helpful. Thirty-five percent indicated trial and error as most helpful, 20% said the vendor, 15% said the manual and trial and error, 15% indicated an unidentified method, and 5% each said reading the manual, an evaluation team member, or a family member. Eighty-three percent indicated they were very satisfied or satisfied with the training and 17% were either dissatisfied or very dissatisfied.

Ninety-one percent of the respondents indicated they were either very satisfied or satisfied with their integrated controller. Four percent indicated that they were neither satisfied nor dissatisfied and 4% indicated that they were dissatisfied.

The respondents were asked on a scale from 1-5 how well they liked gadgets. Five being liked gadgets a lot and one being did not like gadgets at all. Eighty-three percent of the respondents choose a "four" or "five" on the scale, 8% indicated a "three" and 9% indicated a "two" or a "one."

Correlation coefficient were computed for 1) general satisfaction with the number of evaluation sessions, 2) general satisfaction with receipt of devices (one at a time versus all at once), and 3) general satisfaction and gadget appeal. No correlations were demonstrated between satisfaction with number of evaluation sessions or satisfaction with receipt of devices (one at a time versus all at once). However, the correlation coefficient between general satisfaction and gadget appeal was moderate (r=.52)

DISCUSSION

Three areas were identified as leading to satisfaction with the integrated controls from the results of this study. One, the introduction of the integrated controller gave the respondents a method of accessing devices that prior to receiving the integrated controller they were unable to operate. Thus, the integrated controller increased their independence. This may in part explain satisfaction with using the integrated controller.

Two, 55% of the respondents used either trial and error, trial and error and the manual. Thus, approximately half of the respondents trained themselves. Another 30% can be identified as using a helper to train using integrated controller. The other 15% used unidentified training methods. Prior to training it may be useful for the assistive technology team to ask the user how they best learn., or how have they trained on other devices? Do they learn by figuring is out on their own, using a manual, or with another person assistance. This information could could be used by assistive technology teams when recommending training methods. Using training methods that appeal the most to users may increase satisfaction.

Three, individuals who were satisfied with their integrated controller also liked gadgets. An interest in gadgets may predisposed individuals in working with integrated controls and gaining mastery of them.

The respondents in this study were self-selected and volunteers. Therefore, results need to be interpreted cautiously. Further work is needed in order to substantiate these findings. Areas where additional study is needed are 1) increasing the subject pool and 2) studying individuals who abandoned integrated controls.

CONCLUSIONS

This survey demonstrated that persons using integrated controls were generally satisfied with them. This is a useful beginning in this area of research.

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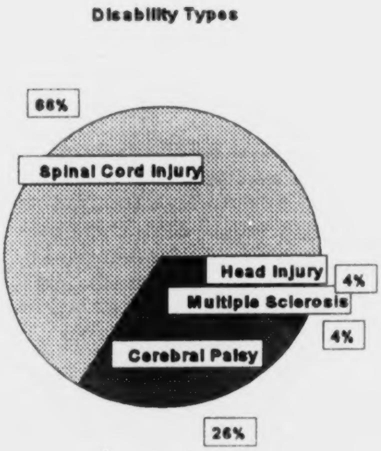

Figure 2

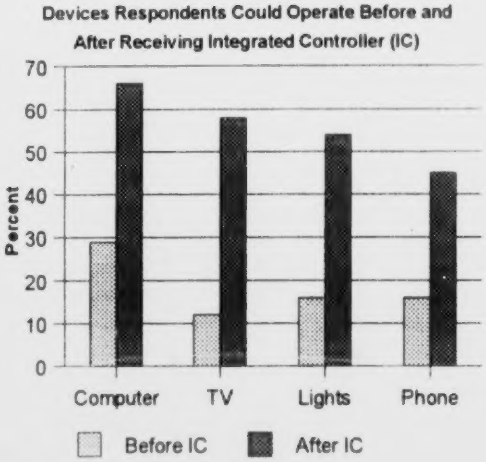

Figure 1

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Computer Simulation of Powered Wheelchair Electro-mechanical Systems

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Abstract

A computer program models the energy consumption of a given powered wheelchair as it traverses a predetermined test course. The model accounts for real world driving conditions. The critical feature is the ability to study the effect of design changes on the performance of the chair, as well as the ability of the design to meet preset goals before going to the prototype stage.

Background

The critical component in a powered wheelchair is the battery which adds considerably to the overall weight of the chair and ultimately determines the performance. The amount of usable charge available from a commercial wheelchair battery depends on a number of factors like variation in loading, the ambient temperature and past cell history. Work has been done to model battery discharge characteristics at University of Virginia [1] using Miners rule to account for the variable loading experienced by the wheelchair battery.

Lawrence Livermore Laboratory has been involved in the comparative evaluation of various electric vehicles. As part of the study a computer model was developed to design a vehicle using aluminum-air cell for the propulsion system and have the vehicle meet a specified mission. The computer code allows for vehicle description and performance information needed for comparisons with many other vehicle propulsion systems[2]. Later Westinghouse Corporation which developed the iron-air battery technology converted the Al-air computer code to an Fe-air computer program [3]. The Fe-air electric vehicle propulsion system is a simple battery-only system which can be used to simulate four standard vehicles defined by Lawrence Livermore Laboratory. The four vehicles a two, four, five passenger and multi-purpose vehicle are described by performance requirements and characteristics like payload and aerodynamic drag. In the Fe-air program for a particular vehicle the designer can select the power/mass ratio and the range over one of eight drive cycles. Using an assumed initial mass the program determines the size of the battery, motor controller and transmission to meet the performance requirements and then drives over the range in one second increments. The components are resized at the end of the drive. If the change in mass is greater than 10 kg. the process is repeated.

Thus while evaluating newer battery technologies it is insufficient to focus only on higher power density as the determining factor for substitution. To evaluate the change in a particular performance feature in a powered wheelchair, for example the range it can travel when the battery is changed can not be determined easily. Thus a systems approach is needed to evaluate new designs or the effect of design modifications on the overall performance of powered wheelchairs. A computer simulation is proposed incorporating some of the ideas developed for electric cars which have been described above, to provide the wheelchair designer the ability to investigate designs before building prototypes.

Method

The powered wheelchair simulation program is intended as a design tool to analyze the effect of varying various parameters on the overall performance of the system and indicate the critical components towards which attention needs to be focused.

This is a discrete analysis where the effect of the mass, overall geometry, ambient temperature, motor characteristics, transmission battery size and type can be investigated. An important feature of this simulation is the ability of the designer to specify a drive cycle to simulate real world conditions the wheelchair is likely to encounter like flat surfaces, grades, turns, accelerations and deceleration's.

The designer inputs into the program are read from the following data files:

General Configuration
- Wheelchair/Occupant mass
- Number of batteries
- Wheelbase geometry definition

Battery data
- Type of battery used
- Mass of the battery
- Battery discharge characteristics for various loads and temperatures

Power train characteristics
- The motor torque/efficiency characteristics and the transmission characteristics

Drive cycle/environment
- The drive cycle
- velocity profiles

- Grades and Rotation
- Surface conditions (hard, low carpet, deep carpet)

The program loops though the drive cycle, which is a discrete (per second) description of the velocity, grade and direction of motion and evaluates the load at each second. The loads on the system is evaluated in watts due to the inertial load (acceleration deceleration), rolling resistance using the type of data obtained by Kauzlarich[4], drag [5], climbing grades and the resistance to rotation (frictional and inertial). The load on the battery is then evaluated by keeping track of the efficiencies of each component of the system. The amount of battery that is discharged is monitored at each instant, normalized for load at the rated value to discharge the battery in six hours (a standard rating for batteries). Individual components are monitored such that they are not overloaded during any part of the prescribed drive cycle.

Some of the useful program outputs are the overall system efficiency, forces acting on each of the wheels during the drive cycle, stability during the cycle and the range for a selected battery configuration.

Results and Discussion

The program has been developed in a modular fashion in 'C', where various subroutine handle inputs, evaluation of component loads etc. A test run was compared to range data available from existing test data [6]. The results where found to be reasonable. Further validation is needed to develop confidence in the simulation program. We plan to monitor the energy consumption over a test track for a instrumented wheelchair and compare it with the simulation program .

Since the program is modular, changes or improvements to the model can be incorporated with ease. Further experimental data is needed to develop a more general description for rolling resistance, possibly as a function of normal load and velocity. The behavior of castors while making turns and its effect on energy consumption needs to be studied. Another issue is the need for drive cycles which represent "typical" usage of a wheelchair. If a few such cycles can be developed it is likely to be very useful for testing wheelchairs designers, and aid consumers in selecting the appropriate wheelchair based on their performance around these cycles. Given the complexities of the issues involved and the need for greater experimental data we are have started the process of contacting industry designers to collaborate with us to refine the model.

We see this collaboration with industry not only as a means of developing a useful design tool , but also as a productive way to educate all parties about what constitutes efficient design of powered wheelchairs.

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JOINT KINEMATICS DURING WHEELCHAIR PROPULSION

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ABSTRACT

The purpose of this study was to describe and characterize elbow and shoulder joint kinematics in three dimensions. Six experienced wheelchair users were filmed with a three camera motion analysis system. Each subject pushed a Quickie 1 wheelchair fitted with a force sensing wheel (SMART^{Wheel}) [1], at two speeds (3 and 5 mph). The elbow angle was analyzed in the sagittal plane, while the shoulder joint was analyzed in the sagittal and frontal plane. There was a significant difference ($p<0.05$) in the mean start shoulder angle and total excursion in the x-y plane and mean start and end angles in the y-z plane when analyzed between the two speeds. The identification of the kinematic components that contribute to an efficient wheelchair propulsion stroke can be used to establish a model for optimizing performance.

INTRODUCTION

The investigation of wheelchair propulsion has become increasingly popular due to the growing population of wheelchair users. The act of wheelchair propulsion has been described as the bilateral, simultaneous, repetitive motion of the upper extremities with the upper extremities primarily going through flexion and extension [2]. Few studies have investigated the joint kinematics of wheelchair propulsion, but those who have, were typically in two dimensions and often visually estimated when the hand impacted and disengaged from the pushrim. Consequently, the exclusive use of kinematic data does not provide the researcher the exact time when the hand impacts or disengages from the pushrim, which may cause inaccuracies in data analysis. With the development of the SMART^{Wheel} [1], we can determine the precise time when the hand impacts and disengages from the pushrim, allowing us to obtain a more distinct measure between the drive and recovery phase of the wheelchair propulsion stroke. The use of the SMART^{Wheel}, in conjunction with kinematic data enables us to obtain more accurate data, specifically related to the joint kinematics. Joint angles at impact and disengagement can be calculated, which can be further used to determine joint excursions and maximum and minimum joint angles during propulsion and recovery. The purpose of this study was to evaluate the shoulder and elbow kinematics for two speeds of wheelchair propulsion.

METHODS

Four male and two female experienced wheelchair users with spinal cord injuries, volunteered and gave informed consent for the study. Each of the subjects pushed on a Quickie 1 wheelchair fitted with the SMART^{Wheel} [1], while secured to a wheelchair dynamometer. The SMART^{Wheel} was used to indicate when the hand applied a force to the pushrim. The subjects pushed the wheelchair at two speeds (3 and 5 mph) for three minutes. A 60 Hz, three-dimensional camera system (Peak Performance Technologies, Inc.) was utilized to collect kinematic data at during the last minute of each trial. A synchronization pulse generated by the kinetic data collection system was utilized to ensure that the video and SMART^{Wheel} data collection were synchronous. Highly reflective spheres used for digitizing purposes were used to identify 7 anatomical landmarks, greater trochater, acromion process, lateral epicondyle of the humerus, radial and ulnar styloid process, and the 2nd and the 5th metacarpalphalangeal joint on each subject. The start angles were defined as the time when force was exerted to the pushrim, while the end angles were the time when the force returned to the baseline. The total excursion of the joints were calculated by the difference between the end and start angles. The elbow in full extension is defined as 180 degrees with the angle decreasing as the elbow flexes. The shoulder angle in the x-y plane is defined as zero degrees when the arm is in the anatomical position. The shoulder x-y angle is positive when flexion occurs at the joint and negative when the joint goes into extension. The shoulder angle in the y-z plane is defined as 90 degrees when the arm is abducted to the horizontal position. The angle decreases as the arm adducts towards the body. The maximum and minimum angles of the elbow and shoulder joint were calculated as the absolute maximum and minimum angle of the joint during the propulsion stroke. Data were analyzed for 5 complete strokes.

RESULTS

Each of the subjects start and end elbow and shoulder angles were analyzed. The shoulder joint was analyzed in two planes, sagittal (x-y plane) and frontal (y-z plane). The total excursion angles of the joints were also analyzed. The mean start elbow angle for the five subjects was 111.86±10.69 degrees for the 3 mph speed and 110.26±10.85 degrees for the 5 mph speed. The mean end elbow angles were 119.72±12.16 and 119.66±13.18 degrees for the 3 and 5 mph, respectively. The mean total elbow excursion for the five subjects were 35.18±12.10 and 32.84±10.76 degrees for the two speeds, respectively. There was no significant difference ($p>0.05$) found in the mean elbow start, end, and total excursion angle when analyzed between the two speeds. The mean starting shoulder angle in the x-y plane measured -49.17±6.93 degrees for the 3 mph speed and -50.15±6.93 degrees for 5 mph. There was a significant difference ($p<0.05$) found in the mean starting shoulder angle when analyzed between speeds. The mean end angle measured -1.81±10.71 and 1.49±9.35 degrees for the 3 and 5 mph speeds, respectively. No significant difference ($p>0.05$) was found in the mean end shoulder angle in the x-y plane when analyzed across speeds. The mean total excursion of the shoulder in the x-y plane was 47.49±9.85 degrees for the 3 mph speed and 51.97±10.14 degrees for 5 mph. A significant difference ($p<0.05$) was found in the mean shoulder excursion angle when analyzed across the two speeds. The mean starting shoulder angle in the y-z plane measured 67.82±5.83 and 72.04±9.63 degrees for the 3 and 5 mph, respectively. The mean end angle for the 3 mph speed measured 41.26±11.88 and 45.60±10.82 degrees for 5 mph. When the mean start and end angles in the y-z plane were analyzed for the two speeds, there was a significant difference ($p<0.05$) found. The mean total excursions in the y-z plane were 27.42±13.94 and 26.85±14.30 degrees for the 3 and 5 mph, respectively. There was no significant difference ($p>0.05$) found in the shoulder excursion angle in the y-z plane when analyzed between the two speeds. When all subjects were analyzed within each speed, a significant difference ($p<0.05$) was found between subjects for all variables, with the exception of the shoulder excursion in the x-y plane. The mean maximum and minimum elbow and shoulder angles were also measured and analyzed. The shoulder joint was analyzed in two planes of movement, the sagittal (x-y plane) and frontal (y-z plane). The mean maximum elbow angle measured 123.24±9.81 degrees for the 3 mph speed and 123.10±10.53 degrees for the 5 mph speed. There was no significant difference ($p>0.05$) found between the mean maximum elbow when analyzed across the two speeds. A significant difference ($p<0.05$) was found between subjects when analyzed within each of the speeds. The mean minimum elbow angle measured 88.12±9.26 and 90.62±8.22 degrees for the 3 and 5 mph speeds, respectively. There was a significant difference ($p<0.05$) found between the mean minimum elbow angle when analyzed between the 3 and 5 mph speeds. When all subjects were analyzed within the 3 and 5 mph speed, a significant difference in the mean minimum elbow angle was found ($p<0.05$) between subjects. The mean maximum and minimum shoulder angles in the x-y and y-z planes coincided with the start and end angles in their respective plane.

DISCUSSION

From the kinematic data, angle-angle plots were graphed for all subjects over five entire strokes. Three different plots were graphed: shoulder x-y angle vs. elbow angle, shoulder x-y angle vs. shoulder y-z angle, and shoulder y-z angle vs. elbow angle, in order to illustrate the sequencing of the elbow and shoulder joints during wheelchair propulsion. A representative set of angle-angle plots for the six subjects are illustrated in figures 1a-c. The shoulder x-y angle vs. elbow angle plot, figure 1a., illustrates that the subjects generally began their propulsion stroke with the shoulder in extension and elbow in flexion. From the plot, it can be seen that the subjects flexed their elbow, while bringing the shoulder into flexion during the initial phases of the stroke. After this point, the shoulder continued to flex while the elbow began to extend in a proportionatal fashion. A transition was seen in the elbow joint during the propulsion phase, which first flexed during the beginning of the stroke to a point near top-dead-center, then began to extend to the end of the stroke. This is supported by Rodgers et al. (1994) findings that EMG activity was primarily detected in the biceps brachii to top-dead-center, then activity in the triceps brachii thereafter. During the beginning of the recovery phase, the subjects primarily flexed

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their elbow, then to a greater extent began to a extend at the shoulder. Near the end of the recovery phase, the subjects continued to extend at the shoulder, but began to flex the elbow again to prepare for the propulsion phase. The shoulder y-z angle vs. elbow angle plot, illustrated in figure 1b., indicates that the subjects generally started their propulsion stroke with the shoulder in abduction and elbow in flexion. The initial phases of the propulsion stroke revealed that the subjects adducted at the shoulder, while slightly flexing the elbow. After this phase, a transition from flexion to extension was seen in the elbow joint, while the shoulder continued to adduct. The end phase of the propulsion stroke illustrated a larger proportion of elbow extension when compared to shoulder adduction.

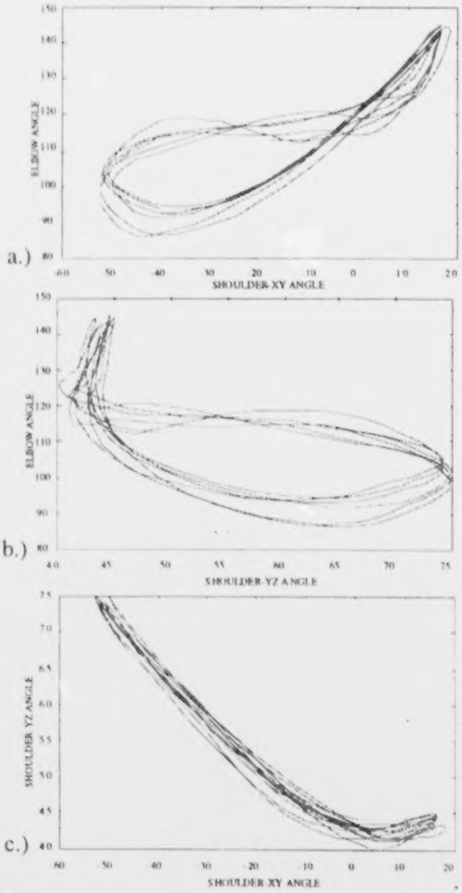

Figure 1a-c. Angle-angle plots for the elbow and shoulder joints for 5 entire strokes.

The initial phase during recovery had a large contribution from elbow flexion with limited shoulder abduction. The remainder of the recovery phase showed a large increase in shoulder abduction with a small contribution from elbow flexion. The shoulder x-y angle vs. shoulder y-z angle in figure 1c., showed a proportionate amount of shoulder flexion and shoulder adduction during the propulsion phase of the stroke. The large contribution of shoulder flexion during the propulsion phase was supported by Rodgers et al. (1994) findings that the anterior deltoid was active throughout this phase. The end of the propulsion stroke exhibited a greater contribution of shoulder flexion with a limited amount of shoulder adduction. The joint angles during the recovery phase of the stroke followed the same relationship as the propulsion phase, but in reverse order.

Angle-angle plots are used to help illustrate and identify inconsistent joint couplings over multiple strokes. This can be used to determine inefficiencies in the user's stroking technique, which in turn, may expose the musculoskeletal structures in the upper extremities to repeated microtraumas. Inconsistencies such as differentially loading the joint structure and abrupt changes in joint angles from stroke-to-stroke can also lead to a dehabilitating injury. The identification of appropriate and erroneous kinematic components that contribute to wheelchair propulsion can be used to establish a model for optimizing wheelchair performance and further relate these characteristics to improve efficiency and prevent injury.

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MODELING THE EFFECTS OF INERTIAL REACTIONS ON OCCUPANTS OF MOVING POWER WHEELCHAIRS

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ABSTRACT

Sagittal torso and arm motions induced by fore-and-aft accelerations in power wheelchairs may adversely affect control performance for people with disabilities. Susceptibility to uncontrolled bucking is an example. A control systems model of this phenomenon has been developed which requires a simplified biomechanical model of the human torso. Experiments have been performed on able bodied human subjects to evaluate the model and to find values for effective torso stiffness and damping. These results are a first step towards understanding potentially dangerous phenomena and specifying clinical guidelines to avoid them.

BACKGROUND

A common problem in the design of mobility-aids for physically challenged individuals is the compromise between stability and responsiveness. While this is a general problem in any feedback control system, it arises for wheelchairs in the following way:

When a person driving a power wheelchair attempts to accelerate the vehicle forward or backward an inertial force acts on his body. If the musculature of the person involved is not strong enough to withstand this force then it may throw the limb manipulating the joystick controller opposite to the direction intended, i.e., backwards while speeding up and forward while braking.. Thus, the vehicle performs the opposite task (e.g., braking when speeding was intended) thereby initiating a similar event train in an opposite sense. This leads to oscillations in the man-machine system which may be sustained or transient. In such a situation, the person may attempt to correct the oscillatory behavior by applying proper muscular effort through voluntary intent. Due to the delays inherent in the system this may actually aggravate the effect instead of correcting for it.

A similar phenomenon of interactive man-machine system instability has been investigated in vivo by Jagocinski et al.,[1] for head-switch equipped power chairs Bennett[2] has investigated the bucking effect using a crude dummy of a hand holding the joystick controller. An analysis has also been performed by Brubaker [3] regarding factors affecting manual wheelchair performance. Power wheelchair controller issues have also been delved into by Cooper[4].

However, in order to quantifiably model such a phenomenon a concise model describing the effect of acceleration of the seat on the upper torso and the joystick hand is required. It has been strongly conjectured by Winter et al.[5] that the human musculoskeletal system components can be functionally modeled as a combination of masses attached to linear springs and dampers. Though characteristics of individual muscles have been thoroughly established study of the performance of multi-jointed systems like the torso have been rare.

RESEARCH QUESTIONS

Long Term

The long term objective of the research is to develop and demonstrate prescriptive procedures for selecting or designing dynamical performance parameters (viz. control systems, joystick characteristics, structural design) for the safe operation of power wheelchairs by severely disabled persons. In order to reach the goal, suitable modeling of the occupant-chair system under significant inertial effects is necessary.

Short Term

In order to develop an objective model of the interactive dynamics of the occupant and the wheelchair, a necessary prerequisite is knowledge of the behavior of human torso as a kinematic system. Though there is ample biomechanical data[6] pertaining to the mass distribution of the torso, no such research has been done for finding the spring and damping constants of the same. The following experiment is aimed at finding the linear spring and damping coefficients that best describe a single degree-of-freedom model of the torso.

METHOD

An experiment has been performed for determining the dynamic behavior of the human torso in the sagittal plane as well as for parameterizing the human-wheelchair interaction in an open-loop scenario.

Setup

An able-bodied human subject was seated in an XPR Arrow™ power wheelchair. The wheelchair joystick output was disconnected from the control system circuitry and an external sinusoidal voltage generator was used to excite the wheelchair at the port receiving the former joystick output. Thus the effective control of the wheelchair was relinquished by the user to the voltage generator. The wheelchair front casters were locked and it was further constrained only in the fore-and-aft direction by a pair of rails. The wheelchair was otherwise conformant to ones in regular use.

Data Collection

The wheelchair was made to move against a graduated planar background. Reflective markers were placed on strategic observable points on the chair and on the human subjects. The entire setup was then recorded on a VHS video camera facing perpendicular to the background. The joystick output and the excitation input were directly recorded on a computer after suitable sampling and digital to analog conversion. An example frame from the videograph is shown in Fig. 1.

Procedure

The subject sat on the wheelchair in a normal posture holding the joystick as one normally would have for controlling the wheelchair, except that she was asked not to perform any voluntary movements. A mechanical restraint was also used on the S's shoulders to prevent protraction and retraction. The wheelchair control was then excited by a sinusoidal voltage signal from the generator. This caused the chair to oscillate linearly along the guide-rails. The S's torso was thus subjected to inertial acceleration due to the oscillatory motion. Because of the motion, the joystick hand of the S experienced a similar motion. However, the joystick being disconnected from the control circuitry, the human-machine loop remained open, enabling separate observation of the control input and the fed-back signal from the machine-man path. Also the motion of the torso in the sagittal plane was recorded by the camera -the reflective markers serving as points of reference. A light bulb positioned in the camera's field of view was controlled by the on-off switch of the voltage generator in order to synchronize the data gathering of the computer and the camera. The excitations were performed at frequencies 0.2 Hz to 1 Hz at intervals of 0.1 Hz and 1Hz to 2 Hz at interval of 0.5 Hz.

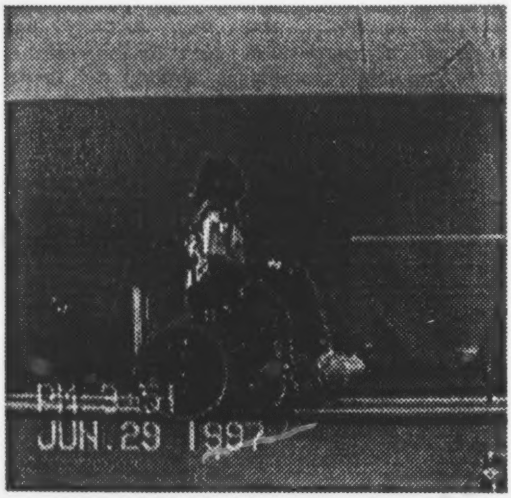

Figure 1: Subject seated in remotely controlled wheelchair during chair oscillation test.

Initial Data Analysis

Pending procurement of the automated digitizer, portions of the videograph has been manually digitized by viewing it in still mode on a high-resolution monitor through a transparent calibrated rectangular grid. The positions of the markers on the S's shoulder and on the axle, wheel rim and pushbar of the chair were noted for each frame of the videograph. The relative movement of the upper torso with respect to the chair and the horizontal velocity of the chair was determined from measured changes in these marker positions.

For small amplitudes of upper torso motion, it can be shown that the torso-wheelchair combination behaves like a linear second-order dynamical system whose frequency response is governed by the transfer function:

$$T(s) = \frac{\Theta_T(s)}{A_c(s)} = \frac{k}{l\left(s^2 + \frac{C}{m\,l^2}\,s + \frac{K - m\,g\,l}{m\,l^2}\right)}$$

where,

m = Mass of torso
l = Height of the center of mass of the torso from pelvic pivot point
k = Ratio of Shoulder height to l
K= Effective rotational spring constant of the torso
C= Effective rotational damping constant of the torso
Θ_T= Angle of inclination of torso
A_C= Linear acceleration of the chair

Among these parameters, K and C were unknown while the rest were obtained from direct observation and anthropometric data.

Since the controller was excited by sinusoidal voltages at various frequencies the velocity dynamics of the chair and hence that of the torso were also roughly sinusoidal at the excitation frequencies.

RESULTS

Estimating the chair velocity and the horizontal relative motion of the torso from the video data and comparing their respective amplitudes and phase at a number of frequencies yielded the observed frequency response of this system shown in Fig. 2. These points were then fitted to a generic second-order frequency response function (theoretical curves shown in Fig. 2) to yield the spring and damping characteristics of the torso (K and C).

The subject used in the experiment was a 150 lb medium dimensioned female whose torso parameters were

Mass = 90 lb
Height of CG from pelvic center of rotation = 18 inches
Rotational spring constant = 558 lb-in/rad
Rotational damping constant = 54 lb-in/rad/sec

As a redundancy check, the parameter k had been kept indeterminate. The fitted equation returned a value of k within 1.25% of the observed value. As a final corroboration of the model, a computer-aided simulation of the experiment was performed using the mechanical parameters obtained. The simulation validated the model within ranges of reasonable experimental error and simulation assumptions (see Fig. 2). Hence, a concise modeling of moderate sagittal movements of the human torso has been performed.

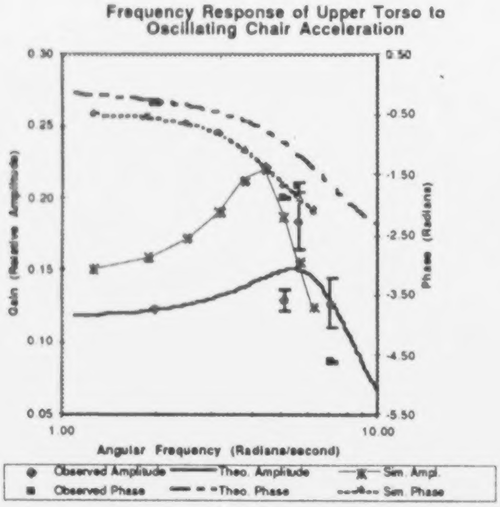

Figure 2: Frequency response of torso. The gain and phase of the transfer function are plotted on separate scales against frequency. Theoretical response has been computed from transfer function equation while the simulated response is obtained from time-step integrated computer simulation of the experiment.

DISCUSSION

The inaccuracies and the data-processing time can be greatly reduced by use of more sophisticated equipment. A good alternative might have been the use of CCD camera equipment usually used in gait labs instead of the regular VHS equipment. Such equipment was not available at the time these experiments were scheduled. Another improvement can be conceived in using an automated frame-grabber instead of manually digitizing the videograph.

Nonetheless the experiment can be considered a success insofar as obtaining reasonable values of spring and damping constants of the torso are concerned. A mechanical mannequin incorporating these kinematic parameters is now under construction. It is hoped that when the mannequin is used as a substitute for a real occupant it will help illuminate various aspects of the system under study, without unduly inconveniencing human subjects. We also plan to use more sophisticated equipment (viz. Vicon™ systems) for these studies on the mannequin.

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MANUAL WHEELCHAIR RIDE COMFORT

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Abstract

Wheelchair ride comfort is a subjective assessment by the wheelchair user of his or her comfort within the wheelchair and environmental system. Static ride comfort involves discomfort as a result of prolonged sitting with minimal movement or prolonged postural deviation. Dynamic ride comfort includes the effects of acceleration and vibration. Due to the lack of wheelchair ride comfort studies, occupational posture, automobile ride comfort, and human vibration studies were investigated to provide various experimental techniques for a wheelchair ride comfort study. The results of this study will optimize rider comfort as well as lead to wheelchairs that are safer and more durable.

Background

The wheelchair user assesses comfort based on the presence of discomfort. Ride vibration, postural support, pressure distribution, ergonomics, and material breathibility are important parameters which affect the user's assessment of comfort. These parameters produce physiological changes in the user's body including circulation and nerve occlusion, ischemia, heat buildup, and visual and auditory interference. These changes result in short term human experiences of discomfort such as pain, annoyance, and displeasure. Additionally, these changes can cause long term damage and deformity such as tissue necrosis, nerve damage, and spinal deformity (1).

Static ride comfort deals with the user's response to prolonged sitting with minimal movement. For example, in an office setting, the user is primarily stationary for most of the work day. Static loads affect the user continually in each position she or he acquires. Posture and postural support are therefore extremely important factors when considering rider comfort. The spinal column supports the upper extremities and compresses under these loads. The loads are transmitted through the spine to the gluteus maximus where continuous pressure can lead to decubitus ulcers. In addition, these compressive loads induce moments, and these moments increase as postural deviation increases. These moments can cause spinal deformities. Seat supports can reduce and redistribute pressure as well as minimize postural deviation.

Dynamic wheelchair applications incorporate accelerations and cyclic loading compounding the existing static loads. For example, wheelchair motion as the result of user propulsion, or propulsion from external forces such as automobile transportation, are illustrations of dynamic situations. During an acceleration, the spinal column acts as a shock absorber, an energy absorber, and a transmission couple for vertical forces. Vibration, especially vibration that is near the first human resonance frequency of 5 Hz, can lead to spinal deformities, herniated discs, and chronic back pain over time. It is important to design wheelchair stiffness and damping characteristics to minimize vibration transmission.

Several studies have been performed examining rider comfort in static and/or dynamic situations. Unfortunately, there has been very little research done in the field of wheelchair rider comfort. Therefore, studies on occupational posture, automobile ride comfort, and human vibration will provide the basis for modeling wheelchair ride comfort experiments.

Genaidy and Karwowski (2) studied the effects of posture deviation on perceived joint discomfort ratings. Nineteen college students performed 24 body movements while seated and were asked to rank the associated discomfort with each movement. The results could be used to modify seats by adding supports that accommodate uncomfortable movements.

Magnusson, *et al.* (3) studied the effect of seat back inclination on spinal height. Previous study showed that the disc pressure and the EMG activity of the erector spinae muscles decreased markedly when the backrest inclination was increased from 90 to 120 degrees. Further decrease of disc pressure and muscular activity occurred through the use of a lumbar support (4). In the Magnusson, *et al.* study twelve women were subjected to 5 minutes of sinusoidal vibration at a frequency of 5 Hz. The women had a 20 minute rest before each exposure. Each woman was seated in a 90, 110, and 120 degree posture and instrumented with a linear displacement voltage transducer. It was found the use of a 110 degree angle backrest caused less height loss than use of a 120 degree angle backrest in a static situation, but the opposite was found for a dynamic situation.

Zimmermann, *et al.* (5) studied the effects of posture on erector spinae EMG activity. 11 male college students were vibrated vertically at 4.5 Hz in three different unsupported postures: neutral upright, forward lean, and posterior lean. Subjects were vibrated for 2 minutes and EMG activity was collected. They concluded posture has a significant effect on the response of the erector muscles. Results showed that posterior lean resulted in decreased EMG and decreased vibration response, and reduction in vibration response yielded decreased disc compression.

Some research has examined the use and comparison of seat suspensions and rider comfort. Wilder, *et al.* (6) studied the effect of posture and seat suspension on discomfort. Six males were subjected to vibration in 2 different seats and three different postures simulating truck driving for 10 minutes. One seat was a standard spring seat; the other seat had a gas spring suspension. The three different postures were leaning forward, sitting upright, and seated back against the backrest. Three uniaxial accelerometers were used to measure the transmission of acceleration. One was placed on the baseplate, one was placed on the seatpan/driver interface, and one was placed on a bite bar. A transfer function gain value less than one signifies attenuation. Gain values greater than one indicate amplification which could lead to mechanical failure. Results revealed amplification in the 4-6 Hz range for all postures except the full-back posture. In addition to acceleration transfer, EMG, and spinal height loss, subjective comfort (using a visual analogue scale) have been used to evaluate and quantify comfort. In the simulated truck driving study performed by Wilder *et al.*, a visual analogue scale was used. It consisted of a continuous 10 cm long line that ranged from 'very comfortable' to 'very uncomfortable'. Subjects marked a point on the line they felt best described their level of comfort and this point corresponded to a numerical value. In the study, the full-back posture yielded the lowest (most comfortable) values, illustrating that subjective comfort may be correlated with an objective measure such as acceleration transmissibility.

Statement of Problem

Many different tools have been used to measure rider comfort, both objective and subjective, but none of these have been used to evaluate wheelchair ride comfort.

Ride comfort will be assessed using a test course. The proposed test course is designed to present a range of normal obstacles that impart road loads. These include curbs, door thresholds, ramps, and pavement joints. A random sample of subjects (minimum n=50) will be used in the test. Each subject will complete the course in three instrumented wheelchairs at three different speeds (0.5 m/s, 1.0 m/s, and 1.5 m/s), yielding at least 150 data sets per obstacle.

Subjective assessment by the user will be addressed by using a visual analogue scale during testing and an evaluation survey before and after testing. The visual analogue scale consists of a ratio scale 10 centimeters in length. Along the scale are numbers with corresponding levels of comfort (most comfortable-most uncomfortable). Ratings will be requested from the user when encountering an obstacle. The user will look at the scale and give a number that best represents his perception of comfort. These values will be correlated with the accelerations imparted to the wheelchair and rider.

Before and after testing, the users will participate in a short interview. The interview prior to testing will assess the user's perceived static comfort of the current wheelchair being used. The interview after testing will assess the wheelchair's performance in the test course.

Implications

By quantifying wheelchair ride comfort, users can benefit in short term and long term situations. Optimization based on subjective and objective results will produce more comfortable and more efficient wheelchairs.

Designs will be incorporated that optimize comfort by considering backrest inclination, frame stiffness and damping, cushion stiffness and damping, lumbar support, and ergonomics. Designs will decrease discomfort incidence by reducing vibration, pressure, and postural deviation, leading to reductions of pressure sores, nerve damage, and spinal deformity.

Discussion

Along with the visual analogue scale, the evaluation surveys before and after testing comprise the subjective tools that will be used in this study. Survey questions will address the wheelchairs' performance characteristics. The following list is a sample of questions:

How well is your back supported?
How often do you have to shift your weight to maintain comfort in this chair?
How bumpy is this wheelchair's ride?
How easy is this wheelchair to propel?

Each question will contain a set of answers with five degrees and be numerically coded from 1 to 5 (i.e. not at all bumpy-1 to extremely bumpy-5). The results from these questions and from the visual analogue scale will comprise the perceived ride comfort correlation data.

Postural deviation, EMG, spinal height loss, and accelerometry are several objective tools which have been used in previous studies. EMG and spinal height loss would be difficult to implement with a user propelling a wheelchair, and therefore will not be considered for this study. Postural deviation will be measured in a static situation and correlated with users' perceived static comfort. Accelerometers will be placed on the wheelchair and an instrumented mouthpiece will be placed in the users' mouths. The recorded accelerations will be correlated with the users' perceived comfort during propulsion through the test course.

Based on previous studies the following parameters will be varied and compared during the 150 test course trials: frame stiffness and damping; and back inclination. Results will be correlated with comfort and acceleration data.

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A SYSTEM FOR THE DESIGN AND ANALYSIS OF SEAT SUPPORT SURFACES

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ABSTRACT

Despite research that now spans decades, the ability to measure the efficacy of seating to minimize the risk for pressure ulcers is still modest at best. There are some promising and even intriguing theoretical constructs, but none have been subjected to rigorous experimental examination. Vacuum consolidation, foam-in-place and other direct shape measurement techniques are commonly used to provide custom cushion or body support surface shapes for specialized seating. However, there is still an urgent need for knowledge that will allow for the systematic design of support surfaces. A system has been developed to quantify the complex relationships among support surface shape, tissue thickness changes and interface pressures. This system allows for the dynamic formulation of an interface contour on the basis of programmable criteria. It was designed to facilitates the study of the relationships between support surface shape and interface pressure, and support surface shape and soft tissue distortion. The design, instrumentation, and results of system performance tests are presented here. The system's surface optimization technique, as evaluated by subject studies, is presented in a subsequent paper. The performance tests showed that the system has the ability and precision to control surface shape while measuring interface pressure distribution.

INTRODUCTION

Although it is popular among clinicians as a criterion for good seating, the measurement of interface pressure has considerable limitations [1]. The most appealing theory is that optimum seating will be achieved when the soft tissues are subjected to the least distortion. However, the problem is quite complex and meaningful measurements of tissue distortion, tissue thickness, shear stress, and tensile and compressive forces have been difficult to obtain. It is worth noting that significant stresses occur within the subcutaneous tissues due to distortion of the tissue from seated loading. The amount of distortion is related to the relative composition of the soft tissues and the extent to which they are distended in different directions from a nominal unloaded condition. In theory, the optimum shape is the one that would minimize the internal tissue stresses and external pressure on the tissue.

Computer aided design (CAD) and computer aided manufacturing (CAM) technology has aided in investigations designed to study the complex relationships between external pressure and soft tissue stress and strain. CAD/CAM technology for lower extremity prostheses and orthotics has received significant attention by researchers and developers. In contrast, much less has been accomplished with respect to application of computer aided shape sensing and automated fabrication technology in customized seating.

Quantitative measurements of the seat contour have been investigated. A passive seating system has been developed that uses polyurethane foams of various stiffness and thickness to quantify contours resulting from the human buttocks and cushion interface [2]. This effort included an investigation of the relationships between interface pressure distribution and contour shapes on typical wheelchair cushions for SCI subjects and able-bodied subjects. The application of measured contour data and CAM techniques has been developed for clinical use of the custom contoured seat cushions for SCI, CP, and elderly persons [3]. Clinical studies have indicated that custom contoured cushions provide better pressure distribution, comfort and stability [4]. Despite these advances, there is still an urgent need for knowledge that will allow for the systematic design of support surfaces. Current practice is often based on a trial and error process whereby support surface shapes are iteratively altered until satisfactory results are obtained.

The computer-aided seating system (CASS) allows for the dynamic formulation of an interface contour on the basis of programmable criteria. Our purpose in developing the closed-loop, dynamically controlled shape and pressure sensing system is to quantify the complex relationships among support surface shape, tissue thickness changes and interface pressures. Change in tissue thickness are inferred from the force-deflection characteristics of the tissue as measured by external pressure per unit change in deflection, i.e., stiffness. In other words, measurement of stiffness is used as an indictor of tissue thickness.

The primary effect of non-uniformly applied force or pressure on the skin is strain in the cutaneous and subcutaneous tissues. The buttocks soft tissue is generally not compressed as a result of support surface reaction forces. If the tissues were contained or pressure was applied hydrostatically, the soft tissues of the buttocks could withstand relatively high pressures without significant risk of tissue damage. Only when pressure is applied non-uniformly are tissues strained and consequently put at risk of tissue damage. While sitting, the soft tissue of the buttocks is not contained, therefore, support surface reaction forces result in such internal strain.

At present, an algorithm based on interface pressure and tissue stiffness is used to drive the system to an "optimized" shape. The broader aims of our research are to quantify the relationship of shape, interface conditions (axial) and tissue distortion (primarily based on stiffness) relative to unloaded shape, lesion level and other relevant factors for stratified populations. The capabilities of the CASS allow for these and other potential investigations.

INSTRUMENTATION

The current CASS represents a second generation design for this system. The development, assembly and testing of the first generation CASS has been previously reported [5,6]. As compared to the first system, this CASS has the ability to adjust surface shape four times more rapidly, measure interface pressure directly at the support surface versus indirectly using force measurements as was done in the first design, and uses updated computing and interface equipment.

The system consists of an instrumented seat support surface for measuring interface pressure and controlling support surface shape, an interface unit for processing the pressure transducer signals and controlling the array of drive motors, and an 80486 DOS compatible personal computer for high level control of the system. The adjustable seat support surface forms a 3-dimensional support surface through selective adjustment to the heights of support elements arranged in an 11 by 12 array. Pressure sensors are fixed in the swiveling heads on top of each support element (see Figure 1).

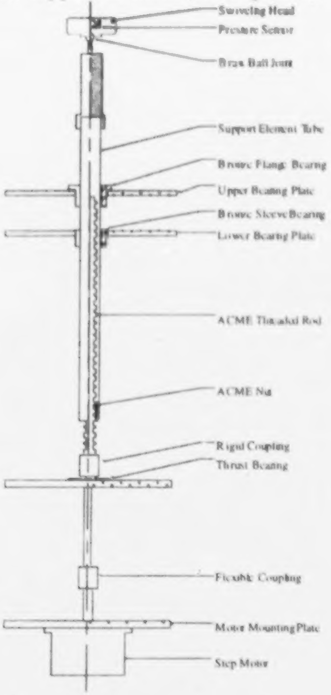

Figure 1. Support element with sensor

The top of the support element rotates freely so that the pressure transducers are oriented in a direction normal to direction of net force. The pressure sensitivity and resolution of the sensor are 0.17 kPa. The 43 cm by 47 cm array of support elements is deployed in a frame consisting of mounting plates for the stepper motor driven linear actuators and bearing plates for the support elements. The vertical position of each support element can be adjusted through its stepper motor driven, lead screw assembly. The range of vertical adjustment is approximately 15 cm.

The interface unit, partially located on the ISA bus of the personal computer, off loads the computers main processor by handling several low level control functions. Low level control of the pressure transducer signal scanning and processing is accomplished using a programmable ISA bus, microprocessor-based data acquisition processor. Low level processing of the motor drive signals is accomplished using an ISA bus stepper motor control board with eight simultaneously and independently controlled channels. The computer hardware and software control the motor array using a 96 channel digital I/O board located on the computer bus, the aforementioned stepper motor controller, and a custom built control signal multiplexing circuit.

Signals from the pressure transducers are continuously scanned by the data acquisition processor and stored locally for recall by the controlling software. Thus, the system controls the height of each of 128 stepper motor driven support elements to alter the support surface shape and has the ability to scan the 128 pressure transducers at a rate of 195 complete scans per second. This capability allows for the open-loop control of support surface shape with or without interface pressure measurements, automatic closed-loop control of interface pressure via control of support surface shape, and/or the characterization of soft tissue in contact with the support elements through monitoring changes in interface pressure conditions relative to changes in support surface shape.

The supporting structure, shown in Figure 2, was designed so that the support surface could be used in a flexible, simulated seating environment. The structure includes an adjustable sling backrest, armrests, and a footrest. Seat depth, seat to back angle, armrest lateral position, armrest vertical position, footrest height and footrest angle are all adjustable.

Core software has been developed to control the motor array, communicate with the data acquisition processor to receive pressure measurements, and display support surface shape and pressure. The core software is expandable to allow for the development of control algorithms using support surface shape and interface pressure as parameters.

SYSTEM PERFORMANCE

In order to demonstrate the ability of the instrumentation to perform the intended application, the various subsystems had to be evaluated and their performance parameters defined or verified. The subsystems that needed analysis were the pressure sensing system and the support element positioning mechanism.

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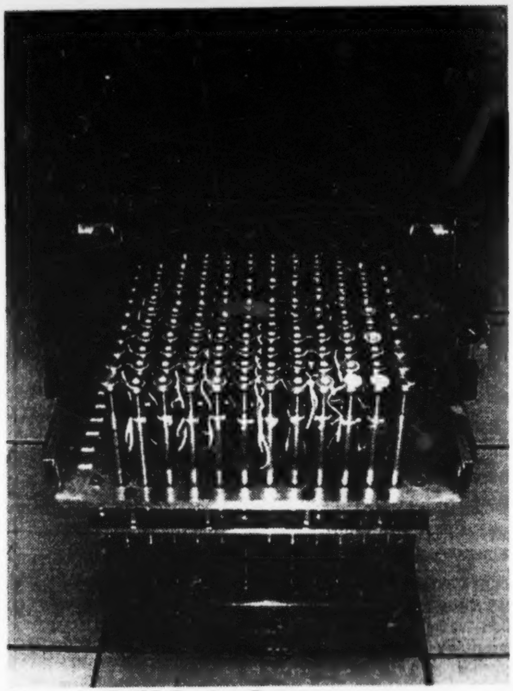

Figure 2. CASS Seating System

A device was developed for calibration of the pressure sensors. A plexiglass tube was used with a thin rubber material covering one end. The height of a water column in the tube applied a known pressure through the rubber membrane. The tube was placed on top of the pressure sensor, perpendicular to and covering the entire sensor's surface. Increasing the height of water in the tube, allowing for known pressure values, the voltage output from the sensor was recorded. In order to reduce the effects of friction, a lubricant, such as ultrasound gel, was used between the rubber membrane and pressure sensor. The linearity of the individual sensors was demonstrated and the maximum error was found to be 8%.

The accuracy of the positioning of the support elements is another important and basic parameter of the seating system. Position accuracy and repeatability under different loads, velocity, step rate, step size and the amount of adjustment will directly affect the convergence of the algorithm, the computation of parameters derived from position changes and the determination of the optimum shape.

An evaluation of the accuracy of the elements' position was determined using a mechanical travel dial indicator. Four sensors were arbitrarily chosen from different locations in the seating system to be evaluated. The test was repeated for variations in starting position, load, step size, and step rate during single step and continuous motion.

The measurement error was minimal for the element in the lower or higher position, while being moved up or down, with an error of less than 2%. The variation in load test results showed that the elements have a small positioning error and good repeatability when the load is less than 45 N. The root-mean-square deviation for 0 to 45 N was from 0.02 to 0.03 mm. For variations in step rate from 100 steps/s to 1500 steps/s, the results indicated good repeatability and small errors for either single step or continuous motion. Positioning errors were determined for step sizes of 0.1 mm, 1 mm, 2 mm, and 10 mm. The deviation from the expected position was found to be less than 0.027 mm with a relative error of less than 5% for step sizes of 1 mm and greater. Overall, the relative error measured for position adjustment can be expected to be 5% or less with a standard deviation of 0.03 mm or less.

CONCLUSION

The system has the ability and precision to control surface shape while measuring interface pressure distribution. The system performance checks clearly indicated that the system is capable of making repeatable and precise measurements of pressure and element deflection and is a reliable tool. The CASS system provides a tool for the investigation and quantification of the complex relationship among the mechanical properties such as shape, interface pressure and tissue deformation under different load and stiffness conditions. This ability is of great significance for clinical study and application. While the CASS itself is not likely to be developed into a viable clinical tool for support surface design, the basic information gathered though its use may prove fundamental to successful design of custom contoured support surfaces.

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EVALUATION OF A SURFACE SHAPE OPTIMIZATION TECHNIQUE FOR CUSTOM CONTOURED CUSHION DESIGN

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ABSTRACT

A system for the design and analysis of seat support and buttock tissue interfaces has been developed. The system has the ability to control the seating surface shape while measuring the external pressure applied to the buttocks by the surface. The system, therefore, facilitates the study of the relationships between support surface shape and interface pressure, and support surface shape and soft tissue distortion. Closed-loop control of the system allows for the dynamic formulation of a support surface on the basis of programmable criteria. The design, instrumentation and system performance test results are presented in a previous paper. This paper presents the basis for and evaluation of a support surface-shape optimization algorithm that has been developed using criteria for the measured parameters of interface pressure and tissue force-deflection characteristics. The technique has been tested on ten able-bodied subjects and 30 elderly subjects. Results presented indicate that resultant optimal support shapes carved into high resiliency foam cushions satisfy optimization criteria, provide lower peak interface pressures than flat foam and the support shape derived from the seated contour only, and reduce the tissue stiffness characteristic.

INTRODUCTION

The computer-aided seating system (CASS) is a dynamically controlled shape and pressure sensing system developed for quantification of the complex relationship between support surface shape, tissue thickness changes and interface pressures. The system consists of an instrumented seat support surface that measures interface pressure while controlling support surface shape, an interface unit for processing the pressure transducer signals and control of the drive motor array, and a DOS compatible personal computer for high level control of the system. The adjustable seat forms a 3-dimensional support surface through selective adjustment to the heights of support elements arranged in an 11 by 12 array. The 43 x 47 cm array of support elements can be adjusted vertically within a range of, approximately, 15 cm. Pressure sensors are fixed into swiveling heads on top of each support element. The top of the support element rotates freely so that the pressure transducers are oriented in a direction normal to direction of net force. The supporting seat structure was designed for flexibility so that the support surface could be used in a simulated seating environment. The structure includes an adjustable sling backrest, armrests, and a footrest. Seat depth, seat to back angle, armrest lateral position, armrest vertical position, footrest height and footrest angle are all adjustable. The system has shown to be a precise, repeatable, and reliable tool.

Software has been developed to control the motor array, communicate with the data acquisition processor to receive pressure measurements, and display support surface shape and pressure. This software is expandable to allow for the development of control algorithms using support surface shape and interface pressure as parameters. At present, an algorithm based on interface pressure and tissue thickness changes is used to drive the system to an "optimized" support surface shape. Tissue thickness changes are inferred from the force-deflection characteristics of the tissue as measured by external pressure per unit change in deflection, i.e., stiffness. The measurement of stiffness is used as an indictor of tissue thickness.

METHODS

This evaluation of the support surface optimization technique is the first to utilize the capabilities of the CASS. In this study an iterative algorithm that optimizes support surface shape using pressure measurements is used. The resulting optimal support surface shape is characterized by a pressure distribution that minimizes the inferred distortion of the buttocks soft tissues from their unloaded shape. The theoretical development of this algorithm is presented in detail in Brienza et al. [1].

Although the CASS system cannot measure unloaded shape or tissue thickness changes relative to thickness in the unloaded condition, this information is inferred from the measurements of tissue stiffness. Tissue stiffness is measured as a change in external pressure per unit change in deflection. Relative soft tissue thickness can be inferred from these stiffness measurements because the load deflection characteristic of soft tissue is such that thinner sections of loaded tissue will appear stiffer than thicker sections under identical loads. Using this property, the algorithm minimizes a quadratic performance index that is a measure of the summation of the gradient of the scaler quantity, stiffness multiplied by pressure, over the array of support elements. The successful minimization of the performance index results in a buttock and support surface interface condition for which the variations in relative distortion of the buttocks soft tissue is minimized. Equivalently a support surface is found for which there is an inverse relationship between the measured external pressure and tissue stiffness. In other words, areas of the support surface in contact with stiffer tissue have proportionately lower external pressures than areas in contact with more compliant tissues.

Surface Shape Optimization Technique

A pilot study was performed on 10 able-bodied persons between the ages of 18 and 40 to demonstrate the CASS performance and to obtain preliminary data on the tissue stiffness based control algorithm. A subsequent study was performed on 30 elderly subjects over the age of 65. The protocol for the study was as follows. The subject first sits on a mechanical seating system with passive spring loaded support elements that deflect under the load of the subjects weight to form the contoured support surface [2]. With assistance from the research team, the subject was positioned in a prescribed seated posture. Once positioned on the mechanical contour measurement device, the resulting shape of the support surface as measured by the deflections on the spring-loaded support elements is stored in the computer's memory. The subject then transfers from the mechanical measurement device to the CASS with the support elements forming a flat surface. Care is taken to ensure that the subject re-establishes the prescribed reproducible seated posture established on the mechanical measurement device.

The iterative optimization algorithm is initiated by recording pressure and stiffness measurements with the support surface configured in the flat condition. After these initial measurements, the support surface elements are moved to form the initial support surface shape previously recorded on the mechanical system. Again, pressure and stiffness measurements are recorded and the support surface shape is adjusted toward the optimum shape as determined by the stiffness and pressure criteria. For each iteration, an optimum pressure distribution is determined from the pressure and stiffness measurements. The differences between the actual and optimum pressures are used to determine the adjustments needed to move toward the optimal support surface shape. After each adjustment, new pressure measurements are compared to optimal pressure values dependent on the optimization criteria. If the measured values are sufficiently close to the optimal values the algorithm has converged; if not, the computer determines the necessary adjustment in support surface shape and another iteration begins.

After determining the optimal support surface shape, the initial and optimal shapes are transferred to a cushion cutting machine that carves the shapes into high resiliency foam cushions. The efficacy of the cushions was evaluated by measuring the distribution of external pressure exerted on the buttocks while seated in the contoured cushion. This was done using a mat containing a 15 by 15 array of resistive sensors that measure pressure (FSA Pad, Vistamed, Manitoba, Canada.) The subject sat on three surfaces of flat foam, the initial contour, and the optimized contour with the FSA mat between the cushion and his or her buttocks.

RESULTS

Figure 1 shows the normalized pressure and stiffness distribution and the quantity of normalized pressure multiplied by normalized stiffness for a test subject. The figure shows these parameters from a single transverse row of support elements passing near to the location of the subject's ischial tuberosities. Data is shown for the first iteration on a flat support surface (iteration 1) and then for selected iterations as the shape is altered by the optimization algorithm until convergence (iteration 10).

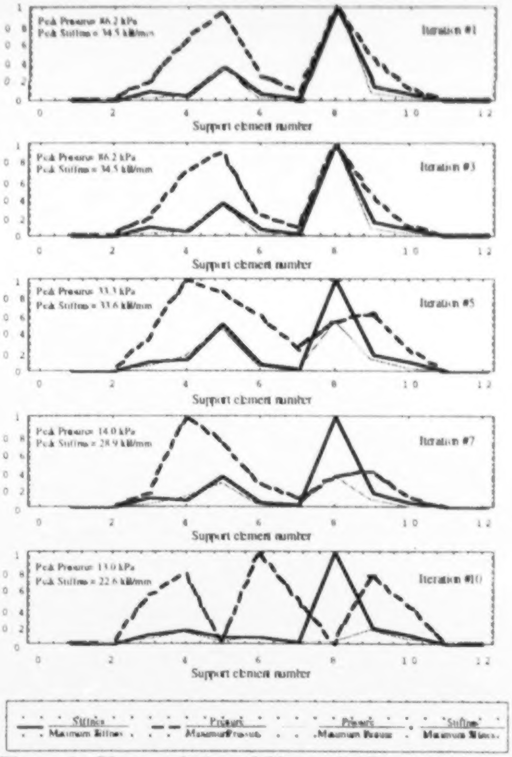

Figure 1. Characteristics of Shape, Stiffness, and Pressure through the Optimization Process

The results of the pilot study are summarized in Tables 1 and 2. Table 1 shows the maximum values of pressure, stiffness and deflection for three support surface shapes: flat, initial contour, and optimal contour, as measured by the CASS during the optimization procedure. Table 2 shows the results of the measurements taken with the pressure mat with the subject seated on the three corresponding foam surfaces. Data was available for only nine of the ten able-bodied research subjects. The external pressure distribution was measured for the three support surface shapes for an initial measurement and a measurement when the subject was repositioned on the surface. The values displayed are the maximum pressure recorded for each condition. The value is the maximum pressure reading of the average of 3 to 5 measurements of a 15 by 15 array of pressures for each condition.

DISCUSSION

Figure 1 demonstrates that the iterative optimization process achieved a support surface shape satisfying the established criteria. Initial and early iterations show that high pressure

PARAMETER	Average
Maximum Pressure (kPa)	
Flat Surface	76.2
Initial Shape	33.3
Optimum Shape	12.8
Maximum Stiffness (kPa/mm)	
Flat Surface	28.6
Initial Shape	25.3
Optimum Shape	13.5
Maximum Deflection (mm)	
Flat Surface	0.0
Initial Shape	25.8
Optimum Shape	41.5
Pressure@Maximum Stiffness (kPa)	
Flat Surface	75.5
Initial Shape	27.4
Optimum Shape	2.6

Table 1. CASS Data from Pilot Experiment

Maximum Pressure (kPa) Surface Shape/Condition	Average
Flat Cushion/Initial Pos.	19.2
Flat Cushion/Repositioned	22.0
Initial Shape/Initial Pos.	14.2
Initial Shape/Repositioned	14.5
Final Shape/Initial Pos.	13.5
Final Shape/Repositioned	13.2

Table 2. FSA Data from Pilot Experiment

measurements coincide with high stiffness measurements. After optimization, higher loads are shifted to support elements where low stiffness measurements are observed. As a measure of the degree to which this condition is achieved, the quantity of pressure times stiffness is observed. The lower the magnitude of this value, the closer the condition is to the optimal condition.

In Table 1, there is an apparent trend in the data with the lowest maximum pressure and stiffness values occurring for the optimal shape, and the largest maximum deflections also occurring for this shape. The maximum pressure (86.17 kPa) and stiffness (34.48 kPa/mm) measured on the CASS for the flat condition are values at the upper limit of the range measured by the pressure transducers and indicate that the actual values exceeded these quantities. Also in Table 1, the data indicating the pressure measured at the location on the seating array where stiffness was maximum illustrates that the algorithm performed as programmed and the inverse relationship between pressure and stiffness for the optimal shape was established. For the flat and initial shapes, maximum pressure is often, if not always, at the location where maximum stiffness is measured. For the optimal shape, the pressure is relatively low at these locations of higher stiffness, verifying that the optimization criteria has been satisfied. Again in pressure mat data in Table 2, a trend in the data is observed where peak pressures decrease from the flat foam to the initial contour and is usually lowest for the optimal contour.

CONCLUSION

The pilot experiments showed that the system's optimization procedure achieved a support surface shape satisfying the established criteria. The results also indicated that the optimal support shapes carved into high resiliency foam cushions provide lower peak interface pressures than flat foam and the support shape derived from the mechanical shape measurement system. The contours resulting from the mechanical shape system are based on the seated contour only and are not modified.

The CASS system provides a useful tool for the investigation and quantification of the complex relationship among properties such as surface shape, interface pressure and tissue deformation under different load and stiffness conditions. This ability is of great significance for clinical study and application. Although the CASS itself is unlikely to be developed into a viable clinical tool for support surface design, the basic information gathered though its use may prove fundamental to successful design of custom contoured support surfaces. The information gained from the study of subject groups at high risk for pressure ulcers, such as the elderly, and persons with spinal cord injury or spina bifida, can be used to further refine and develop the control algorithm. The potential end result would allow application of the algorithm developed for a specific population to data taken from a passive mechanical shape measurement system in the clinic to create an optimized, custom-contoured support surface.

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Three-Dimensional Kinematic Analysis of Racing Wheelchair Propulsion

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ABSTRACT

This paper studied three-dimensional kinematic variables of racing wheelchair propulsion, and how they might improve the efficiency of racing wheelchair propulsion. Kinematic and physiological variables were collected on 6 male wheelchair athletes during 2 trial speeds maintained for 3 minutes. Significant results showed that the high group (HG) had a smaller elbow angle on hand contact (HC), was in contact with the pushrim for a shorter period of time, and had a higher wrist linear velocity on HC. The HG significantly increased their wrist and elbow linear velocities when speed was increased. The results of this study show that as wheelchair velocity increases the more efficient wheelchair propulsion technique incorporates less HC time with the pushrim and increases the wrist and elbow linear velocities which correlates to the 'punching' of the pushrim technique.

BACKGROUND

Athletes with disabilities train just as hard or perhaps even harder than ambulatory athletes. The athletes with disabilities are looking for new and improved ways to train and/or analyze their propulsion technique so that they may improve their performance. The racing times and distances are improving; such that, small increments of improvement could lead to a world record. These athletes are looking for improvements in technology and training techniques in order to improve their performance. The upper extremities have a smaller muscle mass that can make it difficult to develop large forces. van der Woude et al.'s (1) research demonstrated that the gross mechanical efficiency ranged from 2 to 8% for normal daily activities. Grandjean (2) reported that normal walking was 27% efficient. Research has shown that daily wheelchair propulsion is far less efficient than walking (3), but the research of Cooper and Bedi (4) showed that wheelchair racers had a gross mechanical efficiency of over 30%. Assuming that manual wheelchair propulsion might not be efficient for everyday activity, how efficient is wheelchair propulsion for athletic competition? This study investigated kinematic and physiological variables for different efficiency groups to determine which mechanical variables are related to an improved efficiency in racing wheelchair propulsion.

METHODS

Six experienced male wheelchair athletes were used in this study. The kinematic data were collected by using three-dimensional camera view, and then the video was digitized with a motion analysis system (Peak5, Peak Performance Technologies Inc.). The resultant vectors of the wrist and elbow linear velocities were generated by the Pesk5 Analysis System for data analysis. The physiological data were collected simultaneously with the kinematic data using a cardio-pulmonary system (Q-Plex I Cardio-Pulmonary System, Quinton Instrument Co.). The physiological data were used to divide the subjects into high (HG) and low (LG) groups. Table 1 represents the medium (MED) and maximum (MAX) speeds used by the groups for the two trials. Each trial interval was performed for three minutes; however, the last trial continued until the athlete could no longer maintain that speed. The cameras were synchronized one minute into each trial, and this is where the digitization process was started.

	MED	MAX
LG	14 mph	18 mph
HG	16 mph	20 mph

Table 1.

RESULTS

The results of the kinematic data showed that, during the preparatory phase, the HG and LG had similar wrist linear velocity during the MED speed, but the HG increased the wrist linear velocity significantly ($p<0.0001$) for the MAX speed (Figure 1). There was a significant difference

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(p<0.05) between the MED and MAX speeds for both groups.

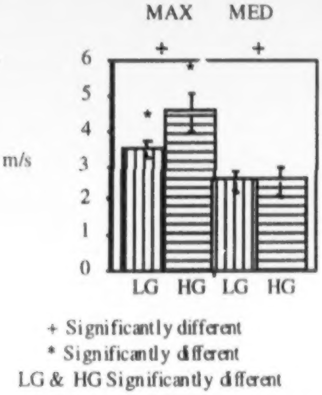

Figure 1. Wrist Velocity During the Preparatory Phase (meters/second)

The elbow linear velocity was significantly different (p<0.0001) for both groups between the MED and MAX speeds. The HG's elbow linear velocity was less then the LG's for the MED speed, but significantly increased (p<0.0001) for the MAX speed (Figure 2).

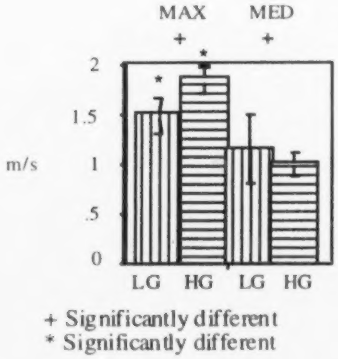

Figure 2. Elbow Velocity During the Preparatory Phase (meters/second)

The time of HC with the pushrim was significantly different (p<0.05) between the MED and MAX speeds for the two groups (Figure 3). The HG's HC time period was significantly less (p<0.0001) then the LG's during the MAX speed trial. There was a significant difference between the two speeds for the groups.

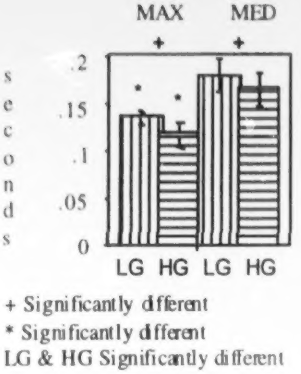

Figure 3. Time Period for Hand Contact with the Pushrim (seconds)

Wrist speed at HC was comparable for the two groups during the MED speed, but the HG significantly increased (p<0.0001) their wrist linear velocity at HC compared to the LG for the MAX speed (Figure 4). There was a significant difference (p<0.05) for both groups between the MED and MAX speeds, and a significant difference (p<0.05) between the HG's speeds when compared to the LG's speeds.

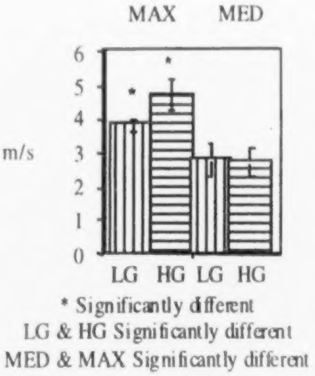

Figure 4. Wrist Velocity on Hand Contact with the Pushrim (meters/second)

DISCUSSION

The arm stroke pattern of wheelchair propulsion was divided into five phases for data analysis: 1) drive hands forward and downward, 2) pushrim contact, 3) hand on pushrim, 4) 'flick' hand off the pushrim, and 5) elbow drive to the top (Robertson et al., 1991). For this study, phase one was considered the preparatory phase, phase two and three were the propulsion phase, and phase four and five were the recovery phase.

During the preparatory phase of the MAX trial, the HG generated a larger velocity with the wrist and elbow to transfer to the pushrim for propulsion. The increased velocities during the preparatory phase helped the HG to have larger velocities on HC. The increased elbow linear velocity during the MAX speed for the HG would contribute to why the wrist speed was significantly increased. The increased velocities on HC and a shorter time period of HC emphasized the 'punching' of the pushrim technique. Studies have shown that this techniqueis a more efficient technique of wheelchair propulsion (Cooper, 1990). The HG's trunk position was more horizontal which enabled them to use gravity to enhance the wrist and elbow velocities on their downward flight to the pushrim.

The high wrist speed on impact with the pushrim could cause a substantial impact spike and shoulder load. If the shoulder strength is insufficient to maintain shoulder stability, injury may occur. This may help explain the high incidence of shoulder injuries to racing wheelchair athletes. Developing a more efficient stroke or adjusting the biomechanical aspects of the racing wheelchair propulsion technique could help the athlete to avoid some injuries. Future studies might investigate the wrist trajectory angle in relationship to the trunk position. The time period of HC with the pushrim can be analyzed with the relationship between the hand trajectory and the trunk position.

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KINEMATIC CHARACTERIZATION OF WHEELCHAIR PROPULSION

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ABSTRACT

There have been numerous studies that have investigated general wheelchair propulsion, although few have analyzed the relationship between the phases and stroke patterns. The purpose of this study was to identify and examine stroke characteristics with changes in speed. Six experienced wheelchair users were filmed with a three camera motion analysis system, while pushing a Quickie 1 wheelchair fitted with a force sensing wheel (SMART^{Wheel}) [1]. Three distinctly different stroke patterns were identified from the kinematic analysis, which were uniquely different from the patterns characterized by previous studies. The PT, RT, CT, and PA were analyzed for six subjects at two speeds (3 and 5 mph). There were significant differences found for all four variables between the two speeds. Our analysis showed that individuals exhibiting a semi-circular stroke pattern may have had the most advantageous stroking technique.

INTRODUCTION

In recent years, the fields of rehabilitative sciences and biomedical engineering have progressively moved towards the investigation of wheelchair propulsion because of the increasing population and high incidence of injury among wheelchair users. There have been a number of studies that have investigated the kinematics of wheelchair propulsion, but there have been very few studies that have investigated and identified characteristic stroke patterns. Cooper et al. (1993) described a method to characterize the wheelchair propulsion stroke by exploiting the periodic nature of the kinematic data taken from a 3-dimensional motion analysis system. The method used in the study fit the optimal, minimum mean squared error, Fourier series to the data. The study identified the appearance of loops in the knuckle trajectories. Sanderson and Sommer (1985) identified two distinct characteristic strokes, pumping and circular. The circular pattern followed the path of the pushrim, while the pumping technique had short abrupt strokes which followed a small arc around the pushrim.

Along with the information regarding characteristic stroke patterns, general phases of wheelchair propulsion should be investigated to better understand how upper extremity segments are used by different individuals. The general phases of wheelchair propulsion can be divided into drive and recovery [3,4]. The drive phase can be identified as the time when the force is exerted to the pushrim, known as push time (PT) [4,5]. The recovery phase can de defined as the non-propulsive phase, when the hand is not in contact with the pushrim, known as recovery time (RT). The sum of PT and RT is equal to the cycle time (CT), equivalent to a complete wheelchair propulsion stroke. van der Woude et al. (1988), and Veeger et al. (1989), determined from kinematic data that PT decreased with increasing speed, while RT remained relatively constant. This caused a decrease in CT. Both studies also found that with increasing speed, no change was observed in the push angle (PA), which remained between 67 and 80 degrees.

METHODS

Six experienced wheelchair users (4 males and 2 females) with spinal cord injuries gave informed consent and volunteered for the study. Each of the subjects pushed on a Quickie 1 wheelchair, secured to a wheelchair dynamometer. The wheelchair was fitted with the SMART^{Wheel} [1] which was used to measure the forces and moments applied to the pushrim. The subjects pushed the wheelchair for three minutes at speeds of 3 and 5 mph. A three camera system (Peak Performance Technologies, Inc.) was utilized to collect kinematic data at 60 Hz during the last minute of each trial. The video and SMART^{Wheel} data collection were synchronized in time by utilizing a synchronization pulse generated by the computer used for kinetic data collection system. Each of the subjects 2nd metacarpalphalangeal joint for five strokes were plotted from the kinematic data in order to characterize the stroke patterns. PT, RT, and CT, were determined by kinetic data analysis. PT was defined as the time when force was exerted to the pushrim, while RT was the time when the force returned to the baseline until the next application of force. The CT was calculated as the sum of PT and RT. The push angle (PA) was calculated as the angle from the time the hand impacted the pushrim to the time off the pushrim. The second metacarpalphalangeal joint was used as the angle of reference to the hub, with zero degrees being the positive x-axis. Data were analyzed for 5 complete strokes.

RESULTS

The general phases of wheelchair propulsion were analyzed for six subjects during five entire propulsion strokes at the two different speeds (3 and 5 mph). The mean PT for the 3 and 5 mph speeds were 0.351±0.073 and 0.229±0.024 seconds, respectively. There was a significant difference ($p<0.05$) found between the two speeds. The mean RT for the six subjects were 0.624±0.141 seconds for the 3 mph speed and 0.604±0.147 for the 5 mph speed. The mean CT was calculated to be 0.997±0.145 and 0.833±0.146 for the 3 and 5 mph speeds, respectively. A significant difference ($p<0.05$) between the two speeds for both RT and CT were found.

The PA was also analyzed for 5 strokes for the six subjects during the two speeds. The mean PA for all six subjects were 89.02±10.62 and 85.86±9.79 degrees for the 3 and 5 mph speeds, respectively. There was a significant difference ($p<0.05$) found between the PA for the two speeds.

Three distinct strokes patterns were identified from the 2nd metacarpalphalangeal joint plots of the six subjects. The strokes were characterized as semi-circular (SC), single looping over propulsion (SLOP), and double looping over propulsion (DLOP) patterns. The subjects exhibiting the SLOP and DLOP patterns lifted their hand over the pushrim during recovery (over the propulsion path), opposed to dropping their hand below the pushrim. Figure 1 a-c illustrates the SC, SLOP, and DLOP patterns, respectively. Two of the six subjects showed a SC pattern, one had a SLOP pattern, and two had a DLOP pattern. One subject had a DLOP pattern at 3 mph and a SLOP pattern at 5 mph.

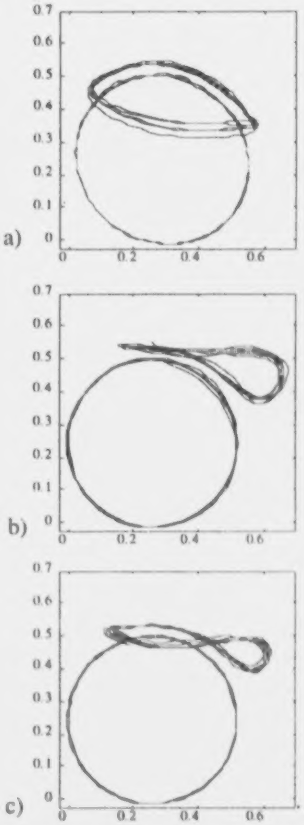

Figure 1a-c. The top plot illustrates the SC stroke pattern. The middle plot represents the SLOP pattern, while the bottom plot is the DLOP pattern.

DISCUSSION

Kinematic data provides the researcher with a mechanism to analyze human movement. The kinematic data only provides a description of the movement, independent of the forces that cause the movement. In our case, video analysis alone can not provide the exact time when force is applied to the pushrim, hence the implementation of kinetic data to determine this. The use of kinematic data in conjunction with kinetic data gives us a more accurate indication of the PT, RT, CT, and PA, which have been visually estimated in past studies.

The results from the analysis of stroke characteristic patterns were distinctly different from the stroke patterns described by Sanderson and Sommer (1985). The circular and pumping style stroke patterns described by the authors were much more simplistic in nature than the patterns observed in our study. It was stated that the circular stroking style was more advantageous than the pumping style because the subject could prolong the propulsive phase of the stroke, producing a greater impulse at the pushrim. Our study showed that the SLOP, DLOP, and SC patterns resulted in no significant differences between each other when PT was analyzed for both speeds. This was also true between all but one subject. This subject was significantly different from all other subjects during the 3 mph speed when RT and CT were analyzed. The subject was the only subject who exhibited a SLOP stroke pattern during the slower speed. During the faster speed, the subjects using a SC stroke pattern had the shortest mean RT and CT, while the subjects exhibiting a SLOP pattern had the longest mean RT and CT. All subjects RT and CT were significantly different from each other, with the exception of one subject (SLOP pattern) showing no significant difference from the two subjects exhibiting a SC stroke pattern.

The subjects with the SC stroke pattern had the largest mean PA, while the subjects with the DLOP had the smallest mean PA. A significant difference was found between the three different stroke patterns when PA was analyzed during the 3 mph speed, with the exception of one subject who exhibited the SLOP stroke pattern. This subject did not significantly differ from the subjects who exhibited the DLOP stroke pattern. During the 5 mph speed, the two subjects with the SC stroke pattern had the largest PA, while the two subjects exhibiting the SLOP had the shortest PA. There was only a significant difference found in the subjects who exhibited the SLOP versus the SC stroke pattern.

Veeger et al. (1989) suggested that subjects could improve their propulsion stroke by extending the PA, to increase the overall percentage of PT. Hence, if the wheelchair user increases the contact time on the pushrim, a larger impulse can be generated due to a greater amount of time allowed for force application. In addition, an increase in the work-cycle, along with a constant PA, can also produce an increase in peak force. Consequently, from our analysis, individuals exhibiting a SC stroke pattern may have had the most advantageous stroking technique, since they had the largest PA when compared to the two other stroke patterns. This may indicate that the SC stroke pattern is the most efficient technique to employ in order to maximize the forward propulsion of the wheelchair. This is not conclusive, but future research must be pursued using kinetic data in conjunction with kinematic data to properly examine wheelchair propulsion characteristics. This information could potentially be used to optimize efficiency, improve pushing technique, and possibly prevent or reduce related injuries.

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FREQUENCY DOMAIN ANALYSIS OF WHEELCHAIR PUSHRIM FORCES AND MOMENTS

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Abstract

The purpose of the paper is to provide a method to analyze pushrim force and moment signals measured during manual wheelchair propulsion. The stem plot of the power spectral density (PSD) provides a graphical means to determine the frequency components of the force and moment signals. Numerical analysis of the PSD's provides a means of determining an estimate of the appropriate filter cut-off frequency. The numerical analysis and cluster analysis were used to select the optimal filter cut-off frequencies for the three dimensional force and moment signals. Signal to noise ratios were calculated based on peak magnitudes, and on root-mean-square (rms) values. The analysis of the force and moment signals provided in this paper provides the basis for future development of digital filters to minimize the effects of additive noise.

Introduction

The development of the SMART^{Wheel} allows researchers to measure the forces and moments developed by a wheelchair user at the pushrim [1,2]. However, the force and moment signals produced by the pushrim propulsion have not been analyzed for their power content or their SNR. The purpose of this paper is to develop the methodology to analyze the signals produced during wheelchair propulsion. The analysis of the signal will allow for the determination of a peak signal to noise ratio and an root mean square SNR. The SNR allows us to determine the effectiveness of the present system to amplify the signal while reducing the noise. It also allows us to determine if changes to the collection of the force and moment data are necessary in order to increase the SNR. The frequency analysis of the signals allows for the estimation of a cut-off frequency. The cut-off frequency will aid in the generation of filters to minimize the noise which may be introduced during the measurement of pushrim forces and moments. Finally, in order to compare the frequency components of one trial to another, frequency groupings were determined, based upon cluster (harmonic) analysis of the power spectral density for each signal [3].

Methods

The analysis of the kinetic data in the frequency domain rather than the time domain, allows for the determination of the key components of the signals produced during the propulsion phase and recovery phase of a complete stroke. Two separate trials, performed by one individual on the SMART^{Wheel} were recorded for the frequency analysis of the push rim force and moment signals. The first trial consisted of the individual propelling the SMART^{Wheel} at approximately 3 m.p.h., and the second trial at approximately 5 m.p.h. Following the recording of the kinetic data, the forces and moments produced on the pushrim of the wheelchair were calculated [4]. From this data, the propulsion phase and recovery phase were separated using the calculated moments about the wheel axle (Mz). The propulsion phase was measured from the point at which the moment about the wheel axle (Mz) deviates from the baseline, to the point at which the moment about the wheel axle (Mz) returns to baseline [1]. The recovery phase is the remainder of the complete stroke cycle. This was done for five consecutive stokes in each trial.

Using Matlab® by The Math Works, Inc. a power spectral density (PSD) was performed on each propulsion phase and recovery phase.

$$S(w) = \mathrm{fft}\,(s(t))$$
$$PSD = S(\omega)\cdot S(\omega)^*$$

Where s is the signal in the time domain, t is time, S is the fast fourier transform (fft) of the signal and ω is the frequency.

The five PSD calculations (one for each stroke in a single trial) were combined to obtain an overall description of the frequency content of the propulsion phase or the recovery phase, respectively. The initial cut-off frequency ($f_{initial\ cut\text{-}off}$) of the propulsion phase was ascertained by determining the largest frequency which has a

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corresponding power value greater than the recovery phase peak power ($P_{peak\ recovery}$).

The power relative to frequency for each propulsion phase was plotted on a single graph, in order to determine the range of frequencies with large power values. For each frequency cluster, the mean and standard deviation of the power as well as the frequency mean and standard deviation were calculated. The clusters were chosen from the PSD stem plots. The optimal cut-off frequency ($f_{optimal\ cut-off}$) was determined by comparing the initial estimate of the cut-off frequency ($f_{initial\ cut-off}$)to the maximum cut-off frequency (f_{max}) determined by cluster analysis.

```
If
    $f_{initial\ cut-off} > \mu(f_{max}) + \sigma(f_{max})$
Then
    $f_{optimal\ cut\ off} = \mu(f_{max}) + 2\sigma(f_{max})$.
Else
    $f_{optimal\ cut-off} = f_{initial\ cut-off}$
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Also, there is a subjective component to determining the optimal cut-off frequency ($f_{optimal\ cut-off}$). That is, if the power signal appears to end well before the $f_{initial\ cut-off}$ then $f_{optimal\ cut-off} = \mu(f_{max}) + 2\sigma(f_{max})$

The peak signal to noise ratio (SNR_{peak}) was determined by calculating the ratio of the maximum magnitude for each propulsion phase ($FM_{peak\ propulsion}$) to the maximum magnitude of each corresponding recovery phase ($FM_{peak\ recovery}$). The root-mean-squared (rms) signal to noise ratio (SNR_{rms}) was determined by calculating the ratio of the rms for each propulsion phase ($FM_{rms\ propulsion}$) to the rms for each corresponding recovery phase ($FM_{rms\ recovery}$).

Results

The method was performed on the kinetic data obtained from a single subject at two speeds. The slow speed was at approximately 3 mph and the fast speed was at approximately 5 mph. The propulsion phase represents the signal, with some additive noise, and the recovery phase represents noise in the force and moment measurements. The mean and standard deviations for the maximum cluster frequencies at 3 mph, and the corresponding cut-off frequencies, using both methods, are presented in Table 1. The mean and standard deviations for the maximum cluster frequencies at 5 mph, and the corresponding cut-off frequencies, using both methods, are presented in Table 2. The optimal cut-off frequencies, which maximize SNR, are bolded in Tables 1 and 2. The signal to noise ratio results are presented in Table 3. In all four cases, the moment about the wheel axle (Mz) had the highest signal to noise ratio.

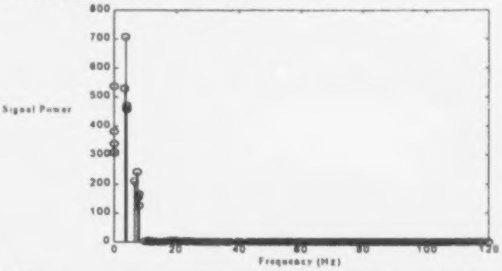

Figure 1. The power spectral density of signal produced by the moment about the wheel axle (Mz).

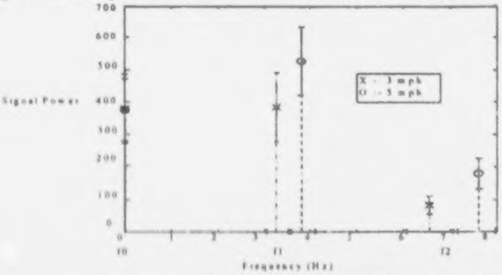

Figure 2. Frequency clusters obtained from the PSD of the signal produced by the moment about the wheel axle (Mz).

Table 1. Frequencies (Hz), for the 3 mph case, used to determine the optimal cut-off frequency. The optimal cut-off frequency is in bold.

Force/ Moment	$f_{initial\ cut-off}$	$\mu(f_{max})$ + $\sigma(f_{max})$	$\mu(f_{max})$ + $2\sigma(f_{max})$
Fx	7.06	7.05	**7.54**
Fy	**11.71**	10.57	11.32
Fz	**20.49**	20.49	20.49
Mx	**23.41**	21.12	21.50
My	**17.56**	9.47	9.87
Mz	23.41	7.05	**7.54**

Table 2. Frequencies (Hz), for the 5 mph case, used to determine the optimal cut-off frequency. The optimal cut-off frequency is in bold.

Force/ Moment	$f_{initial\ cut-off}$	$\mu(f_{max})$ + $\sigma(f_{max})$	$\mu(f_{max})$ + $2\sigma(f_{max})$
Fx	11.8	12.32	**13.21**
Fy	24.41	24.53	**25.67**
Fz	56.95	23.61	**23.61**
Mx	**24.41**	24.35	25.21
My	**19.67**	19.67	19.67
Mz	61.02	8.21	**8.81**

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Table 3. The signal to noise ratios in dB for each force and moment signal measured by the SMART^{Wheel} (mean ± standard deviation).

	Signal to Noise Ratio			
	3 mph		5 mph	
Force/ Moment	SNR_{peak} (dB)	SNR_{rms} (dB)	SNR_{peak} (dB)	SNR_{rms} (dB)
Fx	11.63 ± 2.66	11.72 ± 3.01	10.97 ± 1.79	10.83 ± 1.95
Fy	14.12 ± 3.10	14.96 ± 3.38	19.87 ± 0.96	19.75 ± 0.98
Fz	16.60 ± 2.09	21.15 ± 3.51	16.37 ± 3.32	20.76 ± 1.97
Mx	10.39 ± 1.96	13.04 ± 2.69	12.08 ± 0.89	10.86 ± 0.35
My	15.27 ± 1.45	14.47 ± 1.76	11.84 ± 1.37	12.75 ± 1.49
Mz	27.65 ± 1.75	31.20 ± 1.77	26.03 ± 2.37	30.40 ± 1.58

Example plots of the power spectral density and frequency groupings are shown in figures 1 and 2, respectively. The frequency clusters are smaller for the slower speed (Figure 2). The $f_{optimal\ cut\text{-}off}$ is smaller for the 3 mph trial (table 1) than the 5 mph trial (table 2) except for the moment about the x axis. The signal to noise ratios for the moment about the wheel axle (Mz) are approximately 1.5 to 2 times larger, for all four scenarios (Table 3).

Discussion

The methods described in this paper permit accurate selection of filter frequency parameters for pushrim propulsion forces and moments. The stem plot of the power spectral density provides a graphical means to estimate the frequency components of the force and moment signals (Figure 1). The clustering of frequency components and their corresponding powers into mean and standard deviation values provides the ability to obtain an accurate description of the pushrim force and moment frequency characteristics (Figure 2). This should lead to more appropriate filtering of data, and tools for analyzing force and moment data. Furthermore, the numerical analysis of the power spectral density of the recovery phase to the propulsion phase provides one means of determining the optimal cut-off frequency ($f_{optimal\ cut\text{-}off}$). The cluster analysis method exploits the periodic nature of wheelchair propulsion, and provides an objective means of selecting filter frequencies (Tables 1 and 2).

An optimal approach to describe the frequency component of the force and moment signals produced by the SMART^{Wheel} is to calculate the signal to noise ratio of the signals. Two signal to noise ratios were calculated, one based on the peak magnitude, and the other based on the rms value. The signal to noise ratio improves as the pushrim moments increase within a single trial (e.g., Mz>My>Mx and SNR_{Mz}>SNR_{My}>SNR_{Mx}), except for the mean of the peak SNR for the 5 mph trial. (Table 3). Therefore, the noise magnitude is independent of the applied moment magnitude. The signal to noise ratio is higher in the directions where the sensor is stiffer (i.e. higher natural frequency). The SNR improves with increasing mechanical natural frequency, as the noise is reduced. Also, M_z and F_z are independent of angle, and therefore have lower noise.

The calculation of the power in the individual phases of a complete stroke, provides a more accurate interpretation of the power content at various frequencies. The analysis of the frequency components using the methods described in this paper will allow for the future design of digital filters which will accentuate the force and moment signals produced during manual wheelchair propulsion. Also, the frequency analysis will aid in the creation of methods to reduce the noise present in the force and moment signals.

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WHEELCHAIR PUSHRIM FORCES AS A FUNCTION OF BODY MASS

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Abstract

This study focuses on two aspects of manual wheelchair propulsion: investigation of the possible relationship between body mass and pushrim forces; and simple sinusoidal modeling of pushrim forces. Radial and tangential pushrim forces were isolated for analysis as possibly being functionally related to body mass. Pearson product correlation analysis and linear regression analysis were used to determine if linear relationships existed between each of the model coefficients (k_i's and c_i's) and subject body mass. The body masses of the subjects had a mean and standard deviation of 146.6± 23.5 (N=7) pounds. All models were significantly correlated with their respective forces at $p < 0.05$. Our data indicate that pushrim forces are not highly correlated with body mass. This paper does provide means of analyzing and simulating pushrim forces.

Introduction

Manual wheelchair propulsion is the most common form of mobility for people with lower extremity paralysis. The manual wheelchair transfers mobility from the lower extremities to the upper extremities. This transfer alters the usage patterns of the hands, arms, and torso. It is important in the prescription and set-up of manual wheelchairs to understand how forces are generated and borne by the upper extremities during manual wheelchair propulsion. The understanding of pushrim forces has implications for understanding injury mechanisms, energy efficiency, joint forces, and wheelchair design. This study focuses on two aspects of manual wheelchair propulsion: investigation of the possible relationship between body mass and pushrim forces; and simple sinusoidal modeling of pushrim forces.

Methods

Data from seven people with paraplegia were collected while pushing a manual wheelchair equipped with a SMART$^{\text{Wheel}}$. The SMART$^{\text{Wheel}}$ was used to measure and record pushrim force and moment data. Each subject pushed a Quickie 1 wheelchair, which was secured to a wheelchair dynamometer, at 3 and 5 miles per hour for three minutes. Only data from the last 15 seconds of each time trial were analyzed. Data were collected at 240 Hz per channel, and later low pass filtered at 30 Hz. The body mass of each subject was recorded while seated in a chair placed on a force platform. Body weight was recorded to within 0.25 pounds. All subjects wore spandex tights without foot gear while being weighed.

The radial and tangential pushrim forces were isolated for analysis as being functionally related to body mass. These forces were normalized to 100 percent by using linear interpolation. The stroke length time series arrays were all one hundred elements long (i.e., one percent increments) after normalization. Only the third stroke for each subject for each data set (i.e., 3 and 5 miles per hour) were analyzed. Based on the normalized data, a sine and cosine series was fit to each normalized stroke for both speeds.

$$\hat{F}_{r_{norm}} = \sum_{i=1}^{6} k_i \cos(i\pi t) + k_7$$

$$\hat{F}_{t_{norm}} = \sum_{i=1}^{5} c_i \sin(i\pi t)$$

Pearson product correlation analysis and linear regression analysis were used to determine if linear relationships existed between each of the model coefficients (k_i's and c_i's) and subject body mass. A significance level of $\underline{p} = 0.10$ was used for this preliminary analysis. Homogeneity was assumed between the model coefficients and subject's body mass (i.e., the two variables are related by a constant with no offset term).

Results

The body masses of the subjects had a mean and standard deviation of 146.6± 23.5 (N=7) pounds. The range was from 113 to 176 pounds (i.e., a difference of 63 pounds). The correlation coefficients between the model and normalized radial force ranged from a low of 0.948 to a high of 0.996 for all subjects across both speeds. The correlation coefficients between the model and normalized tangential force ranged from a low of 0.903 to a high of 0.998 for all subjects across both speeds. All models were significantly correlated with their respective forces at $p < 0.05$.

For 3 miles per hour, regression and pearson product correlation analysis showed only one significant correlation between body mass and a model coefficient. This coefficient was c1 ($r^2 = 0.74$, $p < 0.10$) for the normalized tangential force. For the tangential force model the square of pearson product correlation coefficients ranged from $r^2 = 0.0$ to $r^2 = 0.74$, N = 7. For the radial force model the square of the pearson product correlation coefficients ranged from $r^2 = 0.04$ to $r^2 = 0.24$, N = 7. Based upon these results no further analysis was made.

Based upon the mean and standard deviation model coefficient values the radial force normalized to one hundred percent and equalized by body weight can be represented by the following equations:

3 mph

$$\begin{aligned} F_r = [&\left(-1/_{4.6\pm4.1}\right)\cos(\pi t) + \left(1/_{7.7\pm3.9}\right)\cos(2\pi t) \\ &+\left(1/_{3.5\pm17.6}\right)\cos(3\pi t)+\left(1/_{108.6\pm241}\right)\cos(4\pi t) \\ &+\left(1/_{35.4\pm41.4}\right)\cos(5\pi t)+\left(1/_{39.9\pm41.2}\right)\cos(6\pi t) \\ &-\left(1/_{4.3\pm2.8}\right)] \cdot M \end{aligned}$$

$$\begin{aligned} F_t = [&\left(1/_{2.2\pm1.1}\right)\sin(\pi t) + \left(1/_{39.6\pm117.7}\right)\sin(2\pi t) \\ &+\left(1/_{47.2\pm226.7}\right)\sin(3\pi t)+\left(1/_{31.9\pm72.5}\right)\sin(4\pi t) \\ &+\left(1/_{-25.7\pm99.5}\right)\sin(5\pi t)] \cdot M \end{aligned}$$

5 mph

$$\begin{aligned} F_r = [&\left(-1/_{5.8\pm6.6}\right)\cos(\pi t) + \left(1/_{6.2\pm5.0}\right)\cos(2\pi t) \\ &+\left(1/_{327.3\pm853.1}\right)\cos(3\pi t)+\left(1/_{875.5\pm2305}\right)\cos(4\pi t) \\ &-\left(1/_{16.6\pm38.8}\right)\cos(5\pi t)-\left(1/_{15.8\pm66.5}\right)\cos(6\pi t) \\ &-\left(1/_{2.8\pm2.8}\right)] \cdot M \end{aligned}$$

$$\begin{aligned} F_t = [&\left(1/_{1.5\pm0.6}\right)\sin(\pi t) + \left(1/_{1.6\pm8.9}\right)\sin(2\pi t) \\ &-\left(1/_{11.2\pm13.7}\right)\sin(3\pi t)+\left(1/_{6.6\pm51.2}\right)\sin(4\pi t) \\ &-\left(1/_{18.4\pm26.9}\right)\sin(5\pi t)] \cdot M \end{aligned}$$

Several of the model coefficients are near zero (i.e., the mean and our standard deviation values in the denominator terms are large). These terms can be neglected to simplify the model.

Discussion

This study attempts to address two important questions related to the assessment of manual wheelchair propulsion: (1) are pushrim forces related to body mass; and (2) can pushrim forces be modeled as low order sums of sinusoids? We were able to obtain low order sinusoidal models of pushrim tangential and radial forces for each subject. We chose to use orthogonal series (i.e., cosines for radial force, and sines for tangential force), because the radial and tangential forces are along mutually orthogonal axes, and this type of modeling has been successful in modeling ground reaction forces during human bi-pedal locomotion [1]. Simple models of pushrim forces are useful when designing force/moment measuring systems as they provide input data into simulations of the device under design. Simple models may also be useful when examining the effects of various forms of impairment. For example, some forms of impairment may exhibit different frequency components and different coefficient values. Simple mathematical models are also useful for implementing inverse dynamic approaches. These areas require further investigation, and are beyond the scope of this preliminary study.

Our data indicate that pushrim forces are not highly correlated with body mass. During bi-pedal locomotion, ground reaction forces are often normalized to body mass. This is done to examine the percentages of the individual's static body mass borne by the foot and other anatomical structures. Simple models of ground reaction forces have been found to be correlated with body mass, which allows accounting for body mass variations during simulations [2]. Wheelchair propulsion forces may be analyzed as percentages of body mass, as it may be a helpful means of conceptualizing the magnitudes of the forces borne by the hand and other upper extremity structures. The lack of a relationship between body mass and pushrim propulsion forces is not surprising, as a large portion of the individual's body mass is supported by the seat and legrests. Therefore, the magnitude of pushrim forces are likely to be more affected by environmental factors (e.g., rolling resistance, grade). This paper does provide means of analyzing and simulating pushrim forces.

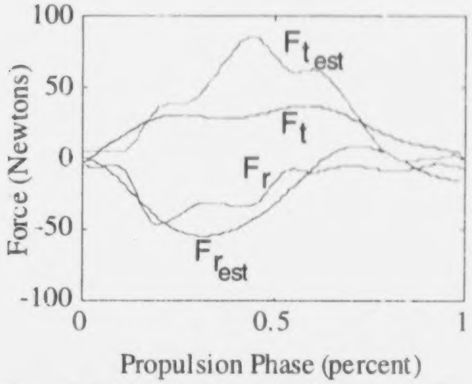

Figure 1. Modeled and actual pushrim radial and tangential forces for a single subject.

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THE RELATIONSHIP BETWEEN THE ANGLE OF CAMBER AND THE TRACKING MISALIGNMENT OF MANUAL WHEELCHAIRS

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ABSTRACT

Wheelchairs with camber on the propelling wheels require accurate setting to achieve tracking alignment. To this setting corresponds a seat/frame trim angle. A change from this seat/frame trim angle setting will cause some degree of rear wheel tracking misalignment. This effect will be greater for larger camber angles and since tracking misalignment increases the rolling resistance it is particularly relevant for sport wheelchairs which can have camber angles up to 20°.
In this paper this effect is quantified and it can be shown that for a camber angle of 10° a change in trim angle of 8° will cause a tracking misalignment of 1.4° corresponding to a toe in/out of 32 mm for a 26 inch wheel.

BACKGROUND

It is recognised that rear wheel camber has an [illegible] the propelling energy required (3). Additionally it has been shown that is necessary to set accurately the rear wheel axis to guarantee the parallel tracking of these wheels (4). Changes of seat/frame trim angle can occur either by, i) raising or lowering the axis of either the front or the rear wheels, ii) lifting the front wheels of the ground during the impulse on the push rims often seen in the riding/racing practice. These changes in trim will inevitably cause some degree of tracking misalignment of the real wheels.
Wheel tracking misalignment will increase the rolling resistance and therefore it is important to quantify and minimise this effect.

OBJECTIVE

The main objective of this study was to identify the relationship between real wheels tracking misalignment and seat/frame trim angle quantifying this effect for different camber angles.

METHOD

Figure 1 show schematically a three wheel "Sports" type wheelchair. The variables shown are: L-the distance between the front and rear axis; β-seat/frame trim angle; H- distance from the ground of the front wheel; γ- wheel tracking misalignment angle.

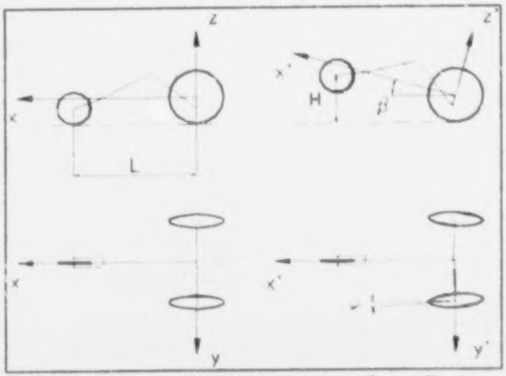

Fig. 1- Show schematically a "Sports" type wheelchair in the vertical and horizontal plane.

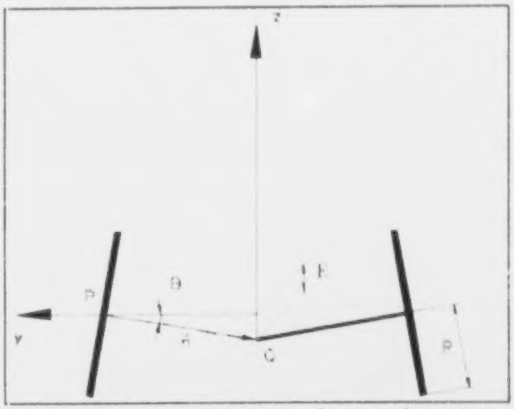

Fig. 2 - Rear view of the back wheels with camber.

Figure 2 shows the geometry of the back wheels. The variables shown are: R - the wheel radius; Q- the intersection point of the wheel axis; E- distance between the horizontal and the intersection point of the wheel axis Q; θ- the camber angle; P- the centre point of the rear wheel hub; $\vec{n}$ - the vector defining the rear wheel axis rotation due to changes in the seat/frame trim angle β.

The co-ordinates of P are defined by:

$$(x,y,z) = \left(0,\ E\frac{\cos\theta}{\sin\theta},\ 0\right)$$

The co-ordinates of Q are defined by:

$$(x,y,z) = (0,0,-E)$$

The vector $\bar{n}$, is given by the difference of co-ordinates between points P and Q:

$$\bar{n} = \left(0, E\frac{\cos\theta}{\sin\theta}, E\right)$$

As the trim angle β is increased the vector $\bar{n}$ takes new positions. These new positions can be defined by a rotation matrix A:

$$A = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix}$$

The new position of the vector $\bar{n}$ after rotation is obtained by:

$$\bar{n}' = [A]\cdot[\bar{n}]$$

$$= \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix} \cdot \begin{bmatrix} 0 \\ E\dfrac{\cos\theta}{\sin\theta} \\ E \end{bmatrix} = \begin{bmatrix} E\sin\beta \\ E\dfrac{\cos\theta}{\sin\theta} \\ E\cos\beta \end{bmatrix}$$

The tracking misalignment angle,γ is obtained by :

$$\gamma = \arccos\left[\frac{\left(E\sin\beta, E\dfrac{\cos\theta}{\sin\theta}\right)\cdot(0,1)}{\left\|\left(E\sin\beta, E\dfrac{\cos\theta}{\sin\theta}\right)\right\|}\right]$$

This expression can be rearranged as:

$$\gamma = \mathrm{arctg}(\mathrm{tg}\theta\cdot\sin\beta) \qquad (1)$$

The trim angle β can be related to the distance of the front wheels from the ground by the following expression:

$$H = (\cos\beta - 1)E + L\sin\beta \qquad (2)$$

The tracking misalignment angle γ can also be converted into tow in/out. For a 26 inch wheel the following expression was used for the conversion

$$\text{Tow in/out} = 4 * R * \sin\gamma \qquad (3)$$

RESULTS

The values of tracking misalignment γ° for different trim angles β° from 0° to 90° and for camber angles θ from 6° to 20° were calculated using expression (1) are shown in table 1. The range of trim angles β° from 0° to 90° were chosen to show the non linearity of this relationship although it is recognised that for normal riding practice trim angles variation will be less than 20°.

β°	γ°	β°	γ°	β°	γ°
0	0	0	0	0	0
15	1.6	15	3,2	15	5,4
30	3	30	6.1	30	10.3
45	4.3	45	8.6	45	14.4
60	5.2	60	10.4	60	17.5
75	5.8	75	11.6	75	19.4
90	6	90	12.0	90	20.0
θ = 6°		θ = 12°		θ = 20°	

Table 1 Values of tracking misalignment γ° for different trim angles β° and camber angles θ.

The figures 3 show the results of table 1 in graphical form.

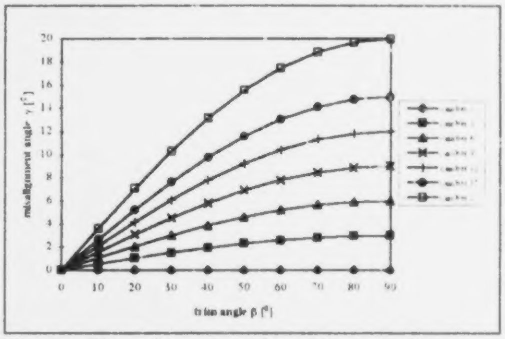

Fig. 3 - Show the value of tracking misalignment γ° for a range of trim values β from 0° to 90° for different camber angles.

The figure 4 shows the values of tracking misalignment γ° corresponding to trim angles up to 20° which represents normal riding practice.

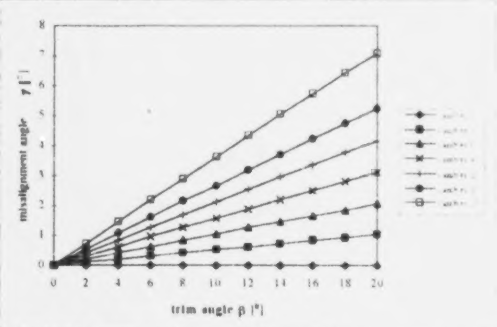

Fig. 4 - Shows the value of tracking misalignment γ° for a range of trim values β from 0° to 20° for different camber angles.

For practical purposes it was considered useful to convert the trim angles β into the distance of the

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front wheels from the ground H using expression (2).

The tracking misalignment angle γ was also converted into tow in/out using expression (3).

Figures 5 and 6 show in graphical form the relationship between distance of the front wheels from the ground H and the tow in/out for a wheel camber θ of 10°.

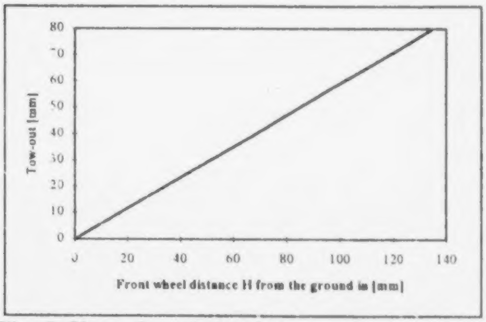

Fig.-5 Show the relation between the tow in/out and H for a "Universal" type wheel chair with a L of 400 mm and a camber angle θ of 10°.

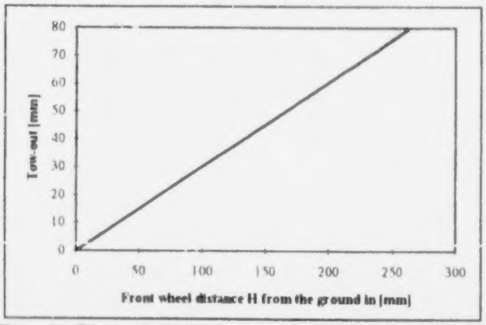

Fig. 6- Show the relation between the tow in/out and H for a Sports type wheelchair with a L of 775 mm and a camber angle of 10°.

DISCUSSION

These results show that for a "Universal" type wheelchair with a camber angle of θ 10° a change in trim angle β of 8° corresponding to a change in H of 55 mm will cause a tow in/out of 32 mm. For "Sports" type wheelchairs the values of misalignment will be reached at approximately the double of the change in H. This is due to fact that the distance between the front and back wheels of the "Sports" type wheel chair is approximately the double of the "Universal" type wheel chair.

It is recommended to limit tow in/out to 12 mm for "Universal" wheelchairs and 6 mm for "Sports" wheelchairs therefore it can be concluded that the setting up of the trim angle of wheelchairs with camber is critical and that changes in trim angle will significantly influence the rolling characteristic and consequently riding confront.

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DEVELOPMENT OF A USER INTERFACE FOR A TOTAL SUPPORT WHEELED WALKER.

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ABSTRACT

With devices that involve human interaction, such as walking aids, it is the interface between the user and the device which determines the success of the product. Many walking aids offer only one type of patient interface, often preventing its application to patients who have less straightforward problems. This paper describes the development of a modular interface system to fit a total support wheeled walker for a child with cerebral palsy, providing greater support and postural control.

BACKGROUND

The project was referred by a physiotherapist working closely with a child at a local special needs school. The spastic diplegia cerebral palsy child had severe learning difficulties and behavioural problems. Associated with these disorders the child had a low attention level, little ability to communicate, became tired quickly and was overweight due to lack of activity.

The child's previous mobility was by crawling on hands and knees. This severely affected his interaction with other pupils and his ability to investigate the surrounding environment. Various commercially available walking devices had previously been tested for suitability in providing a supported walking posture for the child, but no single device provided a successful solution.

A multi-skilled project team was formed to address the problem, consisting of physiotherapist, teacher, care assistant and rehabilitation engineer. The team members were consistent throughout.

STATEMENT OF PROBLEM

1. To investigate the possibility of providing a device to assist in achieving an upright walking posture with the long term aim of reaching independent mobility.

2. To ensure the device provides full body support without causing discomfort to the child, or restricting the child's natural gait. The device would need to be used in many different situations, for general mobility, and for interaction with other people and the environment, in addition to being a useful therapy aid. Clearly the patient must feel safe when in the device and should be easily manoeuvred into and out of the device.

RATIONALE

An initial assessment was carried out to see how the child interacted with a standard walking device already manufactured by the Institute. The child was filmed using the device, which provided a suitable record of the child's posture and walking action. This initial recording provided an excellent control for the whole investigation and was constantly referred to by the project team.

It was clear from this assessment that there were numerous and complex factors influencing the patient's ability to interact with the walker, more than could form the basis of a specification for an ideal design. Therefore, a relatively crude interface test rig was designed allowing an evolutionary design principle to be followed where the project team guided the design of the interface depending on the child's interaction with the test rig.

There were some key points which needed to be specifically addressed when developing a design: ease of patient access; improved pelvic and thoracic support; direction of the patient's body weight through his legs; rectification of his natural sitting posture and improvement to child's gait.

The base framework of the standard walking device provided a steady mobile platform for the patient to be positioned in, and coped with the different environments admirably, i.e., narrow doorways, differing contact surfaces, and so on. The real challenge was to develop a more suitable user interface which would provide the desired features mentioned above.

Concept theory

Figure i illustrates the child's posture when positioned in the standard walker. The idea was to change how the child interacted with the device to produce a more desirable posture, as shown in Figure ii. Certain key areas were focused on to assist in achieving the preferable upright position.

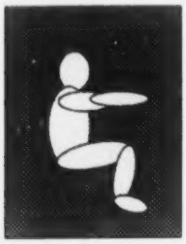

Figure i

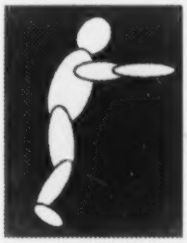

Figure ii

Key areas:
To utilise the child's better upper body strength to help control and support a more upright body position.

To position the body slightly forward in an attempt to achieve a more effective walking action and to direct the patients body weight through his legs.

To provide superior pelvic and thoracic support to assist in maintaining balance.

DESIGN AND DEVELOPMENT

Test rig design
As there were so many unknowns, a relatively crude interface test rig was designed incorporating maximum flexibility, so allowing height, angles and orientations of the patient to be adjusted. Figure iii, gives a simplified diagram of the initial test rig assembly.

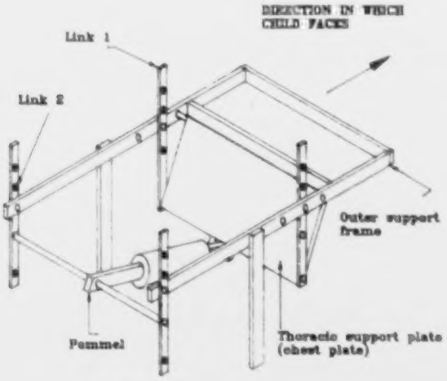
DIRECTION IN WHICH CHILD FACES
Link 1
Link 2
Outer support frame
Pommel
Thoracic support plate (chest plate)

Figure iii.

The test rig design consists of the outer support frame, to which an adjustable thoracic plate is attached. The angle of the plate is adjusted by the supporting link (1), thus changing the angle of the user's upper body. Located centrally at the bottom of the thoracic plate is a pommel. The angle of the pommel is adjusted by link (2) and provides a rigid support for the user. Together, the Pommel and thoracic plate can fully support the user's body in different orientations, but adjusted independently. A safety strap passes around the patient's back and fixes to the angled board.

Evaluation
The child was then assessed in various walking postures within the test frame. The performance and posture of the child were recorded on video during the assessments. Being able to replay the assessments was immensely beneficial when analysing and comparing different interface configurations. The process triggered ideas more easily than merely relying on memory and acted as a superb communication tool within the project team. The 'brain storming' stage of the project could continue away from the patient, thus reducing the assessment time and causing less distress to the patient. All the assessments were carried out with the same members of the project group present. This was to ensure the patient's emotions were consistent throughout, as his behaviour varied with different people.

User trials
When the optimum posture was reached, the configuration/geometry of the test rig was then finalised as a permanent sub-assembly, which attached to the standard walker base. Extensive user trials were then carried out for periods of several weeks at a time. Minor adjustments were made to the structure during these periods to improve the patient's comfort, the ease of positioning him, and refinements to his posture. Each modification to the framework was recorded on video to evaluate any improvement in posture and walking action of the patient. There was an enthusiastic input from the staff members at the School. A logbook was kept on the child's progress, and highlighted areas of difficulty which needed to be addressed. Some of these points were resolved by small alterations to the design. The user trials were continued until no further amendments to the interface were necessary.

RESULTS

The new interface ensured a safe, comfortable, and fully supported upright position for the child to walk independently with. Once a satisfactory posture had been achieved, physiotherapy could begin on improving the child's gait. The child used the device daily for two thirty minute periods and the duration was increased as the child became more capable.

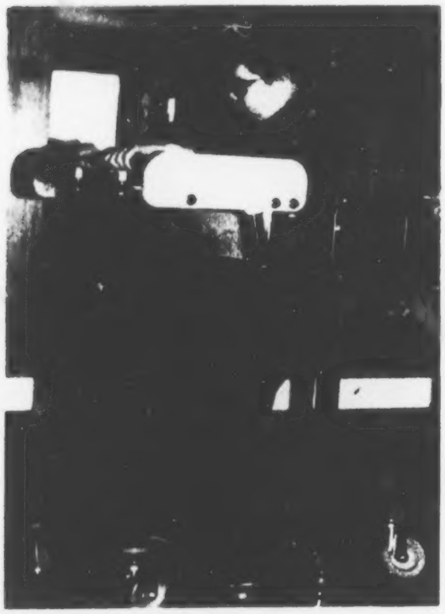

Figure iv.

DISCUSSION

Modular design
A modular design approach was adopted, utilising sub-assemblies from the existing standard walker. This specialised interface sub-assembly provided the correct 'user-device' interaction to support the patient in a superior walking posture as compared with any commercially available walking aids. Adopting this common industrial principle for the user interface has basically produced a device which is attractive to different and larger patient groups.

Future work
Further patients have been referred requiring a total support walking aid. Another prototype test rig has been developed for a slightly different patient group and is awaiting evaluation.

The long term aim is to produce a multi-functional test rig for postural evaluation purposes and from this, possibly, a set of six interface sub-assemblies could be made available to be used with the standard walker base.

Method of evaluation/project approach
There is no doubt that there were two factors in the project procedure that heavily influenced the success of the final result.

Firstly, having a multi-skilled project team ensured that all aspects of the child's background, behaviour and ability were appreciated. This achieved a more accurate analysis of all evaluations.

Secondly, being able to record the patient's posture and interaction with the device, on film, was very effective. This saved valuable time during patient evaluations and the design process. It also minimised any disruption of the patient.

CONCLUSIONS

1. A total support walking device has successfully been developed for a child with spastic diplegia cerebral palsy through designing a completely new user interface.
2. Independent upright mobility is now possible for the first time, and allows the child to interact with his surroundings and other people more easily.
3. The modular design diversifies the product suitability for a larger number of patient types.

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DESIGN AND DEVELOPMENT OF A WHEELCHAIR FOR ENHANCED ACCESS

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ABSTRACT

This paper presents the design and development of a wheelchair incorporating fiber reinforced material technology and a unique combination of features. The design is intended to satisfy a market need for a wheelchair capable of folding compactly for stowing in confined spaces while retaining the performance characteristics that make it suitable for everyday use. The developers expect to exceed the capabilities of commercially available traveling wheelchairs in terms of access to narrow corridors and folding compactness and to provide performance typical of standard, light weight, general purpose wheelchairs. Together, these features work to enhance access for active wheelchair users.

BACKGROUND

As recently as a decade ago, the functionality of wheelchairs was such that many users were limited by unsatisfactory performance characteristics (1). While many, if not most, of the deficiencies in wheelchair designs have been satisfied in the developments of the past decade, greater improvements are possible (2). While wheelchairs are now more functional and generally more dependable, there continues to be a need for greater reliability, lower cost, and more versatility. The primary goal of this project focuses on enhanced accessibility and compatibility for travel. The project was conceived to address these primary issues. Other considerations such as manufacturability, reliability, alternative materials, and others have also been initiated with this project.

STATEMENT OF PROBLEM AND RATIONALE

Environmental access for individuals who depend on wheelchairs for mobility will continue to be an issue for the foreseeable future. This will be the case even with the accomplishments that are expected through advances in universal design. A particular goal of this project is to develop a wheelchair that can meet all the requirements of a general purpose/active use wheelchair and also provide for enhanced access that is frequently needed (e.g., for travel). A wheelchair frame design has been developed and analyzed that folds easily to a very compact size and shape. The user can, while seated in the chair, readily achieve a configuration that permits very narrow access; limited only by the width of the seat support surface.

The goals are to fabricate, and evaluate a general purpose wheelchair that can be easily stowed, manipulated and maneuvered through narrow corridors. Other aspects of the design are the use of molded parts and glass filled polyester material to result in an inexpensive, manufacturable design. Inexpensive molded thermoset materials offer several advantages for use as low cost wheelchair structures. Two major disadvantages are the manufacturers' lack of experience with thermoset molding and the high initial cost of molds. Our experience with one such alternative is summarized in the following section of this paper.

DESIGN AND DEVELOPMENT

The structural elements of the wheelchair were designed as compression molded, glass filled polyester components. This material is extremely inexpensive and is used commonly in industry for electrically insulated structural parts. Since it is an engineered plastic, an entire range of material strengths, weights and costs are available and can be substituted easily for a family of wheelchair products. The geometry was defined by the novel folding structure of the chair and common structural requirements for wheelchairs. The series of wire frame drawings in Fig. 1 depict the conceptual design for the frame and illustrates the folding mechanism. A structural analysis to determine appropriate dimensions to achieve proper material strengths for the different parts was conducted using ANSYS, a finite element analysis program. A few iterations of weight reduction analysis were done on the parts to save some material; much more refinement is possible.

After the parts were produced it was necessary to conduct tests. Not all parts could be molded due to economic constraints. The high cost of mold fabrication precluded mold development for parts other than the side frame. The remaining elements were machined from sheet stock. This decision was made with the knowledge that machined parts will likely have structural strengths on the order of 40% less than comparable molded parts. This loss of strength

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results from surface cracks and defects left from milling the smooth, fiber free surfaces.

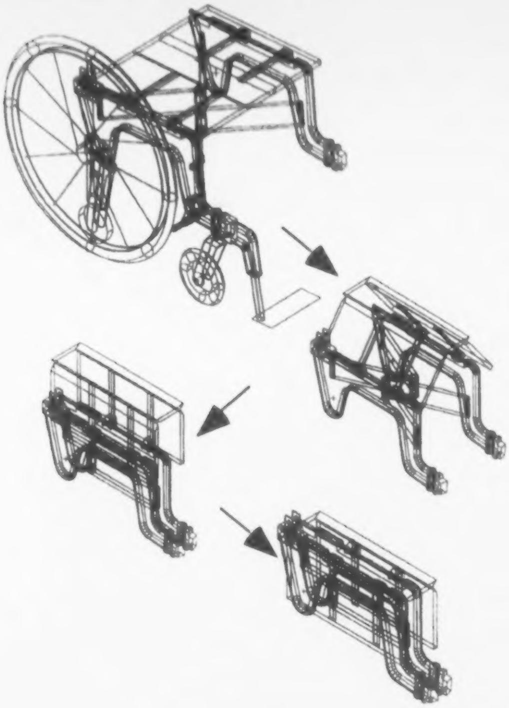

Fig 1 - Conceptual design of frame

The molding technology chosen for this project is based on spray metal tooling. This technique for mold making takes about a month and costs less than $8,000. This process is rather new and has seldom been used on compression molded parts of this size. Only 20 to 150 parts would be expected from this tool. By contrast, standard mold construction for comparable sized parts would require 4 to 6 months to complete and would cost about $70,000. This latter technology could be used to produce 500,000 to 5,000,000 parts. Standard aluminum molds are less expensive ($45,000) and quicker to machine (3 months). This technology is suitable for producing 5,000 to 25,000 parts. The current project provided an opportunity to consider the efficacy of compression molded parts at modest cost. The side frame mold is shown in Fig 2.

EVALUATION

Fabrication of an initial prototype resulted in the discovery of weaknesses in the original design and areas where fine tuning of the design was necessary. As a result of the initial fabrication phase, a substantial number of the components were redesigned with the goal of increasing the structural integrity of the wheelchair frame. The modified designs were used to fabricate two additional prototypes which have subsequently been evaluated using the applicable ISO standard test procedures. The assembled prototype is shown in Fig 3. Figure 4 shows the wheelchair with its main wheels removed for access through very narrow corridors. The doorway shown in the figure is 22" wide.

The first prototype was tested according to ISO 7176-8 (Wheelchairs - Part 8: Requirements and test methods for static impact and fatigue strength). It passed all static impact and strength tests with the exception of armrest upward weight bearing. The armrest upward force test is not applicable to our design because the armrests were designed to release with upward force. The chair successfully completed 200,000 cycles on the two-drum fatigue strength test without failure, but failed after 2055 cycles of the curb drop test. This failure was a fracture of the side frame where the footrest and front caster wheels are attached. Prior to the testing, we observed cracks in the frame developing in this area resulting from a poor fit between the molded side frame and the footrest/caster wheel mount.

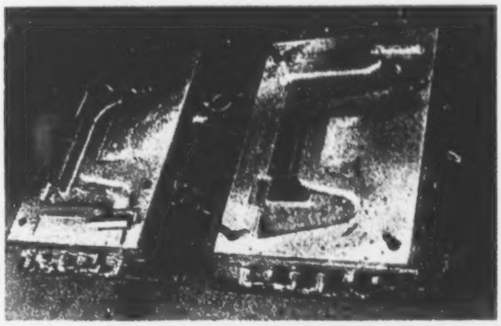

Fig 2 - Side frame mold

Our initial impression of the prototype relative to its performance is positive. The solid seat together with the cross braces and side frame members form a support structure that feels significantly more rigid than typical folding wheelchairs. Even with the large main wheels removed for narrow access, the wheelchair feels sturdy. In informal trials in our laboratory, varying users have found the chair's performance to exceed their expectations for a folding frame wheelchair. A formal beta test program is planned.

DISCUSSION AND CONCLUSION

While there are still several important engineering problems to solve before the eventual development of a commercial product, we have successfully demonstrated the feasibility of producing the wheelchair for enhanced access. Although not our primary objective, we have also shown feasibility of using parts manufactured with inexpensive techniques and materials.

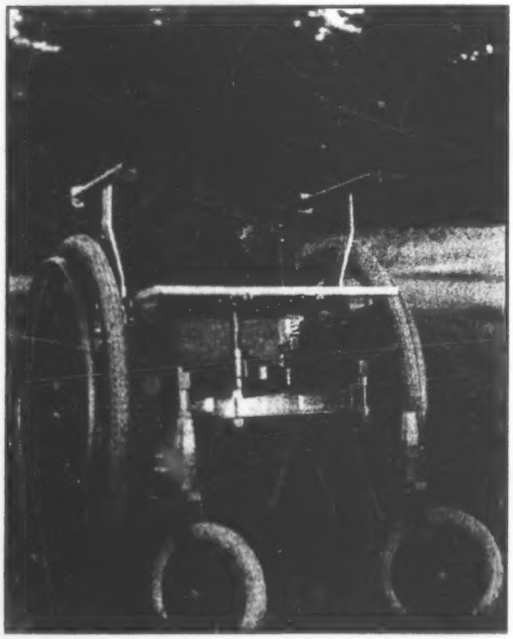

Fig 3 - Prototype shown without footrests

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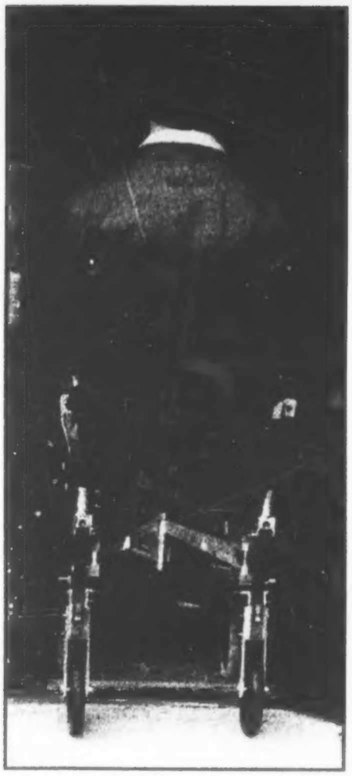

Fig 4 - Access through 22" doorway

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Design development of a new manual prone cart.

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Milwaukee Institute of Art & Design (MIAD), Clement J. Zablocki VAMC, Medical College of Wisconsin; James Haley VAMC, Tampa, FL.

ABSTRACT

Individuals with SCI who use a prone cart for mobility, have identified significant problems with current models. Specifically, prone carts interfere with activities of daily living (ADL) and with socialization. In addition prone carts lack adequate body support for comfort and safety.

The impetus for a new design came from Mr. Schnurr, a service connected veteran with SCI. He formula-ted the idea of a prone cart with an articulated body support to improve comfort and safety. His idea was given to a team of Industrial Design students at MIAD in 1992 with the task of turning it into a product.

Three years later, and several prototypes designed and evaluated along the way, a new manual prone cart is now ready for commer-cialization. The new prone cart features an angle adjustable torso support; a foam contoured body support; a padded front deck with drink holder, for eating, writing and elbow supports and front pull-out storage drawer.

BACKGROUND

Prone carts are used for mobility by individuals with SCI, bedridden for months at a time because of pressure ulcers. Individuals with SCI are at high risk for developing pressure ulcers. Once a pressure sore develops, the patient must stay off affected areas until they are healed, in most instances, precluding the use of a wheelchair. Prone carts provide an alternative to prolonged bed immobilization for patients with ischial or sacral pressure ulcers who must lay on the side or in prone position.

Because of their crude design, and the lack adequate body support for comfort and safety the typical prone carts found around the SCI Center prevent their users to perform simple activities of daily living (ADL). For example it is impossible to eat, write or work from the prone cart. In addition it is extremely difficult to go up or down ramps, go into elevators, into a cafeteria or a store on a prone cart.

STATEMENT OF THE PROBLEM

The development of a new manual prone cart designed to improve the quality of life of patients with pressure ulcers and who use a cart for mobility, was a compelling need.

RATIONALE

The idea for a new design came from a veteran, Mr. Schnurr, who has lived on a prone cart for more than 15 years and from his caregivers at the Milwaukee VA SCI Center. In an attempt to solve the problems associated with living on his old horizontal prone cart, Mr. Schnurr formulated the design for an angled cart. His idea was that by laying down at an angle one could look-up in a comfortable and painless position. Before Mr. Schnurr was in constant back pain from the elevated dorsal position he was assuming on his old horizontal prone cart.

DESIGN and DEVELOPMENT

A team of MIAD senior Industrial Design students was assigned to take Mr. Schnurr' idea with the task of turning it into a product. Working in collaboration with Mr. Schnurr, MIAD faculty and VA SCI clinicians, the students developed concept drawings, and made a 1/4 scale model of a new prone cart. In recognition for this innovative design, an Award of Industrial Design Excellence was presented in 1993, by the Industrial Designers Society of America (IDSA).

From the award winning design and the scale model made by the students, a MIAD design team was involved for the following 18 months to refine the design and fabricate three full size carbon fiber prone carts prototypes. Named the SAMMY LS'S these prone carts were made at MIAD with sponsorship from PVA and EPVA.

The SAMMY LS

The SAMMY LS features: (1) articulated and angle adjustable torso/leg support activated with manually operated hydraulic pumps; (2) contoured bed design; (3) elbow rest; (4) front deck with beverage holder for eating/working; (5) a side pull-out storage drawer; and (6) rear bed extensions with feet protector.

Development of a new prone cart.

Dimensions:
Length: 142 cm (55.90")
Height: 89 cm (35")
Wheel to wheel width: 65 cm (25.6")
Wheel base: 95 cm (37.4")

Propulsion:
Manual with two composite 61.5 cm (24") front wheels with hand rings and two 12.5 cm (5") swivel casters in the back.

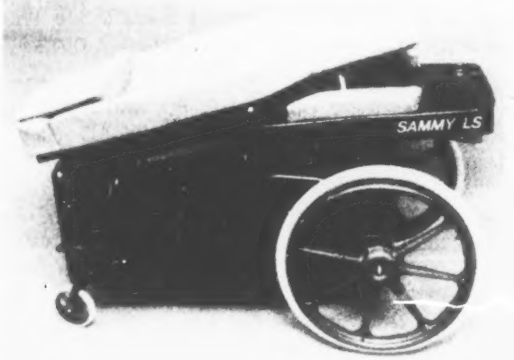
Evaluation:
In addition to Mr. Schnurr who has lived on the first SAMMY LS since 1993, the other "SAMMY LS" prone carts have been in use at the Milwaukee and Tampa VAMC's since that time. Based upon users feed back, the following assessment has been made:

The SAMMY LS is ideally suited for AKA (above knee double amputees, children or short individuals (5 to 25% percentile) and its short wheel base provides easy access to a van equipped with a wheelchair lift.

Positive features: overall bold design, articulated torso support with manually operated hydraulic pumps to vary the angle, contoured bed design, the elbow rest, front deck with beverage holder and for eating /working, height ideally suited for access to public phone, counter tops, etc.

Negative features: when used with the rear extensions, the cart is more difficult to propel because of weight displacement to the rear; the bed support when angled down give users the sensation of sliding off the cart; the side drawer is difficult to reach and use.

The SAMMY LS's



The SCI-PC 22 prone cart

Based upon the evaluation results of the SAMMY LS, another design was undertaken and named the SCI-PC22. Fabricated in 1994 in collaboration with ORTHO-KINETICS, it has a 2.5 cm square steel frame construction to cut the high cost of carbon fiber.

The features of the SCI-PC22 manual prone cart include: (1) angle adjustable torso and leg/bed support, (2) padded front deck with drink holder, for eating, writing and elbow supports, (3) a front pull-out storage drawer, (4) contoured bed design with 5 cm thick naugahyde vinyl covered urethane foam.

Dimensions:
Length: 178 cm (70") Height: 78.75 cm (31")
Wheel to wheel width: 58.5 cm (27")
Wheel base: 104 cm (41")

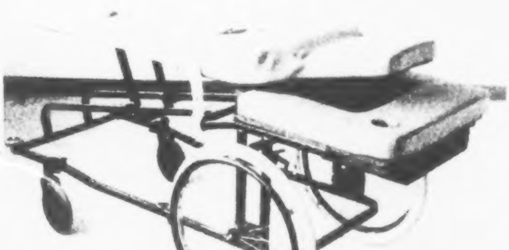
Propulsion:
Manual with two composite 61 cm (24") front wheels with hand rings and two 20 cm (8") swivel casters in the back.

Evaluation:
Based upon user feed back at the Milwaukee and Tampa VAMC's the following assessment of the SCI-PC 22 has been made:

Positive features: overall length; ease of mobility; improved weight distribution; articulated torso support; padded front deck with beverage holder and for eating/working; contoured bed design, elbow rests; height ideally suited for access to public phone, tables, counter tops, etc.

Negative features: the length prevents access to van wheelchair lift, the leg support when angled down give users the sensation of sliding off the cart and no area for urine and/or osmotic bags is provided.

The SCI-PC 22 prone cart



Development of a new prone cart.

The SCI-PC 23 prone cart

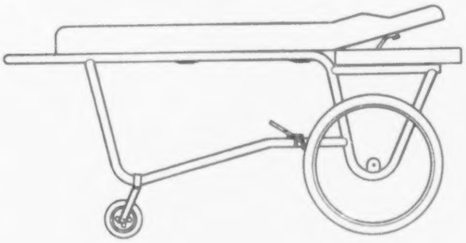
Based upon the evaluation results of the SCI-PC 22, refinements of the design were made for fabrication with 3.80 cm (1.5") steel tubing.

The features of the SCI-PC 23 manual prone cart include: (1) angled adjustable torso support, (2) padded front deck with drink holder, for eating, writing and elbow supports, (3) a front pull-out storage drawer, (4) contoured bed design with 5 cm thick naugahyde vinyl covered urethane foam, (5) a removable section for urine and/or osmotic bags, (6) a frame that forms an all around protective bumper and a foot guard.

Dimensions:
Length: 190.5 cm (75") Height: 76.4 cm (30")
Wheel to wheel width: 75 cm (29.5")
Wheel base: 106 cm (42")

Propulsion:
Manual with two composite 61 cm (24") front wheels with hand rings and two 20 cm (8") swivel casters in the back.

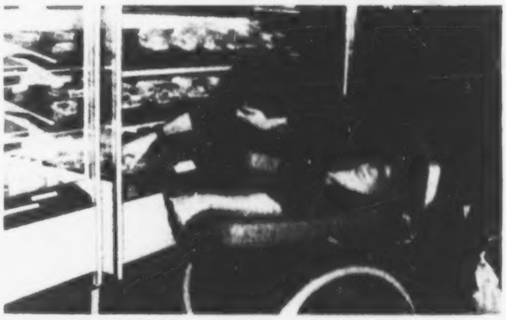
The SCI-PC 23 prone cart



DISCUSSION

This project clearly illustrated that a team effort between users, clinicians, designers and a manufacturer, all involved in solving a much needed mobility patient need can lead to the successful design of a new product.

The outcome of this team effort is that first two SCI-PC 23 prone carts were ordered in the fall of 1995 to Ortho-Kinetics by the SCI Center at the Milwaukee VAMC.



ACKNOWLEDGMENTS

Funding for this project was provided by EPVA, (Eastern Paralyzed Veterans Association), PVA, (Paralyzed Veterans of America), Wisconsin PVA, Mr. Schnurr, VA Rehabilitation R&D Service, and NIDRR, (National Institute of Disability and Rehabilitation Research). In addition the authors wish to sincerely thank Ortho-Kinetics Inc. for their assistance in the development of a new manual prone cart.

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DOOR-OPENING DEVICE FOR WHEELCHAIR USERS

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ABSTRACT

Disabled individuals often have difficulties opening doors for themselves, and commercial door opening devices are very expensive for the typical homeowner. In this project, an affordable door-opening device was created. This is an electro-mechanical system operated on the exterior of the building by a keypad and on the inside of the building by a button. Construction, testing and evaluation of the model was completed in compliance with the codes and regulations applicable to public facilities.

BACKGROUND

Title III of the 1990 Americans with Disabilities Act (ADA) requires businesses to have doorways and doors which are easily accessible to those with physical disabilities. In addition to providing ways around the stairways that approach many entrances, doors themselves must be designed such that they can be easily opened. Many businesses have solved this problem with commercially available systems which cost $1000-$1500 (1). However, disabled individuals also require access to their homes, and the cost of a commercial door-opening system is prohibitively expensive for many individuals.

STATEMENT OF THE PROBLEM

The purpose of this project was to design a device costing $300 or less which can open a typical residential door. The device should comply with the codes and regulations for public buildings.

RATIONALE

To understand the issues of this project, research was done on applicable codes and regulations as well as existing devices. To be a useful device, the door must remain fully functional for the nondisabled population. Therefore, only minimal modifications can be made to the door itself.

The primary source of information on accessibility for the disabled was the ADA (2). Regarding access to doorways, ADA requires:

- 32 in. minimum clear width opening
- 3-5 lb maximum door opening force
- 3 second minimum opening time
- 15 lb maximum force to stop door movement
- 90° minimum opening angle
- easy-to-use door hardware (doors with lever handles, etc.)

The Life Safety Code (3) was consulted to determine the following safety requirements:

- In the event of power failure, door may be opened manually for safe means of egress. (Section 5-2.1.9.1)
- If a power-operated door is used as an exit, it must swing by manual means. (Section 5-2.1.9.2)

DESIGN

Development of Design Criteria

In addition to ADA regulations, a group of wheelchair users were contacted to discuss problems that they had with residential and commercially available doors. Their comments included:

- turning door knob, pushing or pulling on door requires significant upper-body strength
- assistance required from another individual
- operating door independently leads to wear and tear on door, doorjamb, and wheelchair
- inability to efficiently open door restricts means of entrance and egress
- purchasing a commercial door-opening device requires a significant financial investment

The door-opening device was designed to address these issues.

The design consists of an electrically controlled system that is operated manually by the wheelchair user with a keypad on the outside wall and a push-button on the inside wall. This system, shown in Figure 1,

- eliminates unintentional activation of the opening device
- removes the opening and closing load from the disabled individual

- eliminates the need for assistance
- requires little upper-body strength
- allows the user freedom to move without obstruction from the door and doorjamb, thus preventing damage to the wheelchair

Linkage Mechanism

The linkage connecting the door and the frame consists of a telescoping mechanism. As shown in Figure 2, a simple linear bearing allows the arm to extend and retract with smooth operation. The components of the mechanism include a ball plunger/detent configuration (break-away mechanism), sliding shaft stock, and an AB down rod (essentially the same as galvanized pipe) with a PVC sleeve insert.

Electrical Components

The electrical components are placed in a box, shown in Figure 3, which is placed above the door frame so that it does not interfere with the mechanical operation of the door. The electrical components include: control relays, motor, capacitor, limit switches, transformer, and an electric door strike. The motor was sized according to the ADA regulations regarding opening time and force.

To minimize the cost of the door-opening device, parts and materials were purchased at a local hardware store and wholesale distributors. The device was designed to minimize machining time and effort.

DEVELOPMENT

A construction, assembly, and installation guide was written to discuss the procedures used and necessary parts, materials, and tools for the door-opening device. The device was demonstrated as a Senior Mechanical Engineering Design Clinic Project. It was evaluated based on repeatability, ease of operation, ease of manufacture, and required number of modifications to the door and the door environment.

EVALUATION

After assembly the door-opening device was installed on a standard residential door composed of steel casing with a foam-core insert. To provide stability, a wall section was constructed and used for support. This prototype device works reliably and allows easy access for a disabled individual to his/her home. All of the codes and regulations for entrances to public buildings were met. Most importantly with respect to safety, the door can be operated manually during a power failure.

The door-opening device described in this paper costs about $300 to build. Machining was minimal, requiring only a small amount of welding and other basic machine-shop operations.

The only modifications were to the structure around the door as opposed to the door itself. The box containing the electronics was installed above the door frame. The keypad allowing entrance would be installed on the outer wall of the building, and the button allowing egress would be installed on an inner wall. All of the electrical wiring would go through the wall to the door-opening device.

DISCUSSION

The resulting semi-automatic door-opening device met all of the design criteria. However, several modifications could be made to improve the device.

The ball plunger/detent configuration did not work as expected, although the door can still be used in the event of power failure. One possibility for improving the design would be the use of a clutch to engage and disengage the motor and allow for a break-away device. A timed-delay could be implemented into the circuit. This would allow for escape for someone who is trapped in the path of the door. The device would operate if the proximity piece did not strike one of the limit switches within a pre-set time. Additionally, a stronger motor with more running torque would reduce maintenance and extend the motor life.

There is a significant need for a door-opening device for disabled homeowners. With the modifications described above, this device could be a realistic solution.

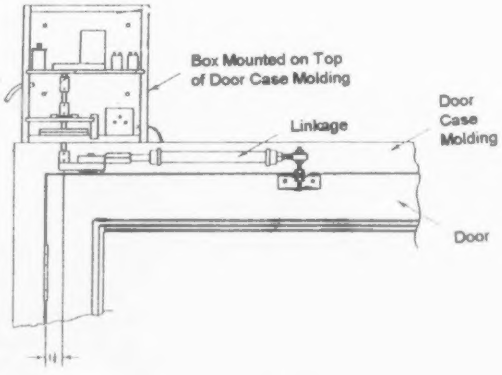

Figure 1. Door-Opening Device Assembly

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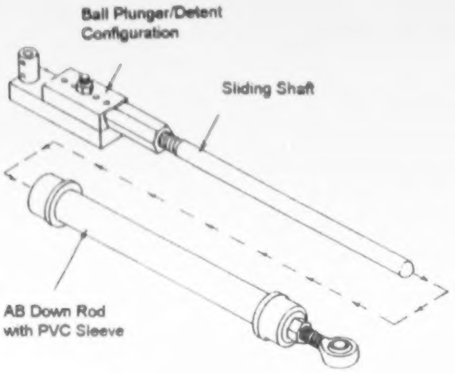
Ball Plunger/Detent Configuration
Sliding Shaft
AB Down Rod with PVC Sleeve

Figure 2. Linkage Mechanism

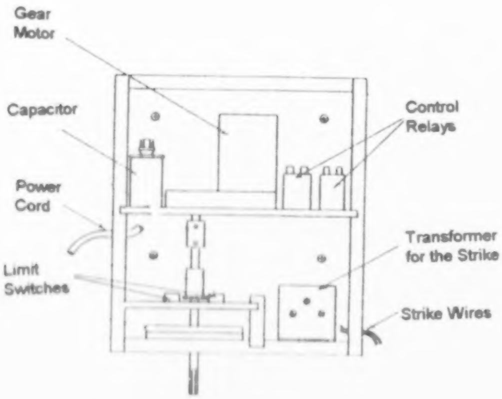
Gear Motor
Capacitor
Power Cord
Limit Switches
Control Relays
Transformer for the Strike
Strike Wires

Figure 3. Electrical Components

REFERENCES

1. Mr. Robert L. Todd, M.S., C.R.C., Information Specialist, Georgia Institute of Technology, Atlanta, Georgia.
2. Americans with Disabilities Act [ANSI-A117.1-1986, Section 4.13]
3. Life Safety Code [101-12, Sections 5-2.1.9.1 and 5-2.1.9.2]

ACKNOWLEDGMENTS

We wish to express sincere appreciation to the Mechanical Engineering Department, the Design Clinic, and the following individuals at The University of Alabama, Tuscaloosa, Alabama:

- Dr. Steve Kavanaugh, Associate Professor, Department of Mechanical Engineering [faculty advisor]
- Dr. Joey Parker, Associate Professor, Department of Mechanical Engineering [faculty advisor]
- The mechanicians of Engineering Technical Services
- Mr. James Sanders, Departmental Technician, Department of Mechanical Engineering [machining of parts]

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A USER ACCESSIBLE REAR MOUNTED STORAGE DEVICE FOR WHEELED MOBILITY USERS

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ABSTRACT

Wheelchair mounted storage devices suffer from a number of shortcomings including difficulty of access for the user or unacceptable changes to the overall width or length of the chair. this paper will describe a simple method used to modify an existing box to allow full user accessibility while maintaining chair dimensions.

BACKGROUND

Our patient is an eleven year old elementary school student diagnosed with cerebral palsy, quadraplegia with mild involvement of the upper extremities, slightly more profound on the right side than the left. She is seated in a Quickie P110 power chair and drives using a proportional joystick with her left hand. An A.B.S. book box was fitted to the back canes of her chair using Miller's quick release hardware. The size of the box was such that it did not increase the overall dimensions of the chair but its location made it impossible for her to access it independently. It was decided that independent access to this device was necessary and that modification of the box was needed.

APPROACH

Attempts to relocate the box were unsuccessful because mounting the box on the side made the chair too wide for doorways. The only viable alternative was to hinge the box so that it was mounted in its present location but could be swung out for ease of access. The first attempt was to attach a single hinge directly to the back cane and the box. This resulted in limited access because the box did not come far enough forward to reach inside the box easily. The second design utilized two hinge points, one at the back cane and the other at the rear corner of the box. This method allowed the box to come much further forward and closer to the armrest.

METHODS

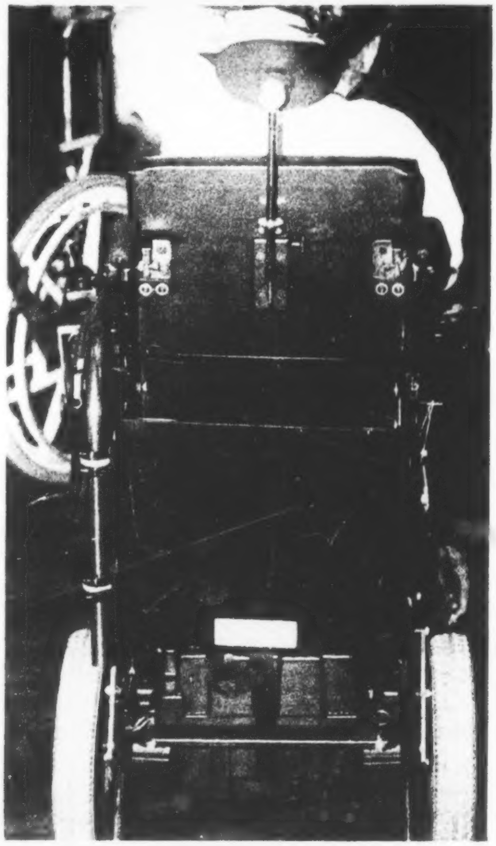
The hinge was made using shaft collars and 7/8" and 1" stainless tubing and the latch mechanism was fabricated in a design much like a gate latch and accessed under the right armrest. A spring was used to open the box when the latch was released so that the box could be reached for opening more easily. A stop was also added to each of the hinges to make the articulation and the latching more reliable. A stop pad was then added to the chair frame to keep the box from damaging the joystick/control box when fully opened.

RESULTS

These modifications have allowed the user totally independent use of the book box while adding nothing to the overall width of the chair when latched closed. The mechanism was tested with ten pounds of weight and still worked as described. The latch mechanism was accessible with either hand and reliably latched closed with a firm shove from the left hand. This box was later transferred to her manual chair when her power chair was in for repairs and similar results were obtained.

DISCUSSION

The single most important path to social acceptance for persons with disabilities is to achieve the highest degree of physical independence possible. Accessibility is often the key to this independence. This is especially true in the case of school age children. The modifications described in this paper have given this student total independence in her school day by eliminating her dependence on her teacher to access all of her school materials. Prior to these modifications, her teachers reported that it was common to interrupt their classes multiple times daily to attend to the special needs of this student. They now report that all of these interruptions have been eliminated by this simple form of accessibility.



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A COMPLIANT SEATING SYSTEM FOR A CHILD WITH EXTENSOR SPASMS.

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ABSTRACT

A child with severe extensor spasms was very difficult to seat because of his movements. He was extremely uncomfortable in a rigid seating system and any constraint to his movements made him extend even harder. A seating system is described which has moveable support surfaces that are connected to a sprung linkage mechanism. This construction allows the child's extensor movements to take place, and then gently returns him to a stable position. The same philosophy is used for other restraining components such as shoulder straps by using elasticated neoprene fabric.

BACKGROUND

A number of children have presented with severe extensor spasms involving their whole body that make it very difficult to seat them comfortably. [illegible] only comfortable in their relaxed state. As soon as they try to extend they push against the seating surfaces and cause themselves much pain. In addition, the mere fact that the support surfaces form an immovable barrier to their movements seems to make them extend all the harder. Such children are often only comfortable when they are sat on a carers lap. In this situation the carer will allow the child to move when he extends. When the child relaxes the carer will gently encourage the child back to a stable position again. This paper describes a seating system that was developed for an individual child to help in this situation by emulating the movements of the carer.

OBJECTIVES

An alternative form of seating is needed which behaves more like the carer and moves with the child. The support surfaces need to articulate relative to each other, following the child's movements, and providing a gentle returning force which encourages the child back to stable position when he relaxes. This compliance needs to be provided whilst maintaining the security of the child.

APPROACH

The child for whom the initial device was developed was most comfortable when he had his legs folded up into a tight 'Z'shape. When he extended he articulated about his hips, pushing back with his upper body, and pushing forward with his thighs. A seating system was designed that provided support surfaces that initially held him in this favoured relaxed position. However the surfaces were hinged relative to each other so that the back surface could hinge backwards and the thigh board could hinge forward. These movements were linked via a four-bar linkage mechanism and the mechanism contained an adjustable spring. The spring held the support surfaces against stops. In this way the normal position of the seat was the child's favoured position, and there was some initial resistance to movement dependant on the resting extension of the spring as it was held against the stops. When the child extended, the support surfaces moved with him; when he relaxed, the spring loaded mechanism gently returned him back to his stable position again. The spring tension and the position of the stops could be adjusted.

RESULTS

The seat was extremely well received by the child. His initial reaction was one of feeling a little insecure because of the seats movement but he became reassured within a matter of minutes. After that, and for the first time for several years, he was able to sit comfortably on his own. Anecdotally the severity of his spasms were also reduced after a few weeks use of the chair.

DISCUSSION

We found that the tension in the spring and the way the tension changed with the movement of the support surfaces was quite critical for the child. Too low a tension and the spring could not return him to a stable position. Too high and the resistance provided had the same effect as the rigid supports and encouraged the spasm. It was important to have adjustment of the tension to help tailor the seat to the individual. As with all work requiring development to suit the needs of an individual, the use of video recordings kept a good record of progress and also provided an invaluable tool to help the engineer make appropriate changes to the design.

A second seat was made for the same child to fit onto a wheelchair base. In the second seat gas struts were used to provide the return force but these proved to be unsatisfactory. It appeared that the intrinsic damping of the gas struts had some impact on the "feel" of the seat for the child. This exercise underlined the importance of the subjective reaction of the child to the movements that took place. Any excessive reaction on the part of the support surfaces to the child's movements seemed to provide feedback which exacerbated the reflex contractions

The technique of using compliant supports was extended to the child's arms. Independently to his whole body movements he tended to contract his arms up into his face, often causing injury. Rigid arm restraints again caused him pain because the very rigidity of the constraint made him contract all the more. Arm supports were therefore constructed from neoprene fabric, the sort of material used for wetsuits. The strong elasticity of this material was ideal in providing a restraint but at the same time providing some compliance to initially allow arm movements but then to return them to a resting position.

The neoprene has proved to be valuable in other ways. The child often had smaller independent spasms where his shoulders would bilaterally extend forward. It was found that restraining straps over his shoulders to keep his upper body stable were again very uncomfortable unless they were constructed from the neoprene fabric. The neoprene allowed some movement of his shoulders but, as with the arm supports, they pulled him back to a stable position when he relaxed.

It is felt that the approach used with this child of providing compliant support surfaces and constraints serves to reduce extensor spams through allowing some movement, and to make the child very much more comfortable.

ACKNOWLEDGEMENTS

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Portable Seating Orthosis for an Adult Ambulatory Scoliosis Patient

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ABSTRACT

Custom seating and positioning systems have been developed and utilized by persons who use wheelchairs. Proper positioning and use of these commercial and custom systems in a static "wheelchair" environment is not new. The challenge in this case presentation is to develop a portable seating orthosis for an ambulatory consumer who would like to use the system in a variety of chairs in a variety of setting, including the consumer's ultimate goal of returning to work.

BACKGROUND

Mary is a 29 year old woman with a diagnosis of multiple congenital anomalies of the spine, thoracic-costal dysplasis and Klippel-Feil association. Her brother is similarly involved and this was most likely inherited from there father who had known spinal deformities.

Figure #1

X-rays show multiple abnormal thoracic vertebral bodies with butterfly type deformities, right thoracolumbar scoliosis, C2-C3 fusion, bony stenosis at C3, open disc space between C3 and C4 and between C4 and C5, fusion of C5-C6, and probably C7. There is a narrowing of the spinal cord distance at the level of C5. Mary demonstrates decreased strength and range of motion in hip abduction, adduction, internal and external rotation. She has decreased hamstring flexibility with increased hip extension range of motion. Upper extremities present with decreased strength in shoulder rotators bilaterally. Sitting characterized by a pelvic obliquity (right side lower), left lumbar, right thoracic and left cervical fixed curves.

Mary has a long history of intermittent neck pain radiating down her right arm. Over the past 2 years she has experienced increasing back pain, and has had to stop working full time as a preschool teacher. She has received intervals of physical therapy treatment for her back pain with improvement, but then experiences a recurrence of the pain. She received a plastic TLSO in 1/93 to support her spine and prevent further deformities. When using the TLSO she reports relief from the pain, but there is little carryover when she is out of the brace.

OBJECTIVE

Mary was seen at the Assistive Technology Center (ATEC) at Spaulding Rehabilitation Hospital in April of 1995 for evaluation for a portable seating orthosis to support her spine when she is not using her TLSO. She wanted a device that would work on any chair and would be easy to carry and set up.

Thereby allowing her to be independent in using the device.

METHOD

Prior to her evaluation at ATEC, Mary had received a Contour U Molded back (See Figure #1). The problems with this back were:

1. It was free standing without a frame and it was difficult to get the correct height and orientation.
2. It was held in position by the pressure of her back against it. There were no straps or any way to secure it resulting in misalignment. Also, if she moved, the back fell off the chair.
3. The back didn't offer any support or relief.
4. The back was too heavy for her to carry alone. She needed the assistance of another person to carry it for her.

During her evaluation at ATEC, Mary experimented with several commercially available backs (Jay, Jay Modular, Jay 2, ROHO, Special Health Systems, and SHS Ultimate) without success. Mary stated that her only relief when out of the TLSO was to sit in an over-stuffed chair which is located in her home. She stated that this chair "engulfed and supported" her allowing her to rest. Because of her need to be mobile she found that the commercial backs were too heavy for portable use. Also, the commercial systems did not provide sufficient support, did not reduce fatigue due to the effects of gravity "pulling down" on her spine, and she experienced some degree of pain with each. Since Mary wishes to return to work she requested a lightweight system that she could transport daily.

During the evaluation, through the use of simulation, it was found that Mary needed 10 - 20 degrees of tilt to reduce the effects of gravity when sitting. It was also found that the commercial systems did not give enough support for her where it was needed and a custom molded seat back would be necessary. In addition to the above, the system must also include a molded seat surface to compensate for her fixed pelvic obliquity (See Figure #2) and decrease her need to use trunk musculature to balance the right side of her pelvis.

RESULTS

The physical therapist designed a portable seating system.

Figure #2

The ATEC design requirements:

1. Molded seat and back
2. Rigid frame that could be secured to various chairs
3. Lightweight with the ability to be carried independently
4. 10 degrees of tilt to take the spine out of the line of gravity allowing some of the weight bearing force to be directed posteriorly through the back
5. Allow Mary to be able to function and maintain the use of her upper extremities

Since ATEC doesn't have in house fabrication facilities it was necessary to make arrangements with a local vendor that provides custom fabrication services. The vendor chosen was Design-Able, of Raynham, MA. An initial fitting was done with Design-Able. Measurements were taken and material brainstorming was done. Design-Able developed the final specifications for design and fabrication of the system and ATEC was given a price quote.

Prior approval was obtained from the insurance company for the portable seating orthosis. Mary and the physical therapist scheduled a date to go to the vendor's facility to perform the molding. It was found during the molding, using the Silhouette Simulator that a 5 degree of tilt would be sufficient for relief. Extra support was needed along her right lumbar area. With the Silhouette system we were able to change the amount of support (by manually

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moving the individual sensors), and we found the optimal amount for Mary.

The following are the specifications of the final seating system:

1. Pin Dot Silhouette cushion for the molded seat back.
2. Kydex for the rigid base.
3. AEL Quick Link hardware for portability.
4. The whole system will be attached to chairs with straps and fastex buckles.

CONCLUSIONS

Mary has not yet received the portable setting orthosis as of this date. It is expected that delivery will take place December 13, 1995. The physical therapist will be involved with delivery of the system and follow up to ensure that the system works as expected.

Expected problems are:

1. The device will not fit every chair. Mary has been made aware of this and is planning on having specific chairs at home and at work (when she returns) to use with the device. She states that she feels it would be better to have the device on some of the time than to only have the option of the over-stuffed chair at home.
2. It is possible that she will fatigue due to over work of her neck muscles being tilted back. There may be the need to add a head rest component.

These problems will be corrected during follow up visits to ATEC.

At the time this paper was written the device was not delivered.

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SIG-10
Electrical Stimulation

THE COMPARISON OF FES TO ORTHOSES FOR UPRIGHT MOBILITY IN CHILDREN AND ADOLESCENTS WITH SPINAL CORD INJURIES

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ABSTRACT

As part of a larger study on lower extremity applications of functional electrical stimulation (FES), a laboratory-based comparison of the utility of a FES system to the utility of knee-ankle-foot orthoses (KAFOs) is being conducted for a standard set of mobility activities. Following FES and KAFO training, five repeated measures of independence level and time to completion are obtained on eight activities with FES and with KAFOs. The median independence score of each activity is obtained with FES and with KAFOs. The mean of the time score is calculated and a t-test is applied to determine if there is a significant difference between FES and KAFOs. Results of the first subject demonstrated that FES and KAFOs provided the same level of independence for seven of the eight mobility activities. For five activities, FES performance required significantly less time as compared to KAFOs. These pilot data suggest that FES was comparable to KAFOs in terms of independence level in the selected mobility activities and may have provided an advantage over KAFOs for some activities by decreasing the amount of time required.

BACKGROUND

Between 1986 and 1991, nine adolescents participated in a laboratory-based study of FES for reciprocal ambulation [1]. As part of this study, pediatric candidacy for FES systems was defined [2] and the effects of exercise and weightbearing with FES on bone mineral density [3], joint integrity [4] and muscle strength and endurance were studied.

In 1991, the focus of the research on FES for lower extremity applications shifted from reciprocal ambulation to upright mobility. Between 1991 and 1994, five adolescents with SCI participated in a feasibility study of FES for upright mobility in the laboratory and their home environments [5]. Implementation of the FES system involved implantation of percutaneous intramuscular electrodes, participation in a four week program of stimulated exercise to reverse the effects of disuse atrophy and participation in a rigorous program of balance and mobility skills training. After four months of training, participants demonstrated the ability to use FES to perform wheelchair transfers to and from cars, high stools and the floor, step up a curb and a flight of stairs, negotiate small areas inaccessible from a wheelchair, reach high places and perform activities at a counter top while standing. These data suggested that FES is a feasible method to provide upright mobility skills for adolescents with complete paraplegia secondary to spinal cord injuries. However, it remains unknown how FES compares to other methods available for upright mobility.

RESEARCH QUESTION

How does FES compare to KAFOs in the independent and timely performance of mobility activities in children and adolescents with complete paraplegia secondary to spinal cord injury?

METHODS

Selection Criteria

Candidates are invited to participate if they meet the following selection criteria: (1) between 6 and 18 years of age, (2) intact lower motor neurons innervating lower extremity muscles required for FES, as confirmed by strength-duration curves, (3) < 30^0 hip flexion and < 15^0 knee flexion and ankle plantar flexion contractures, (4) motor complete SCI between T1 and T12 and, (5) no outstanding orthopedic problems or medical complications.

Implementation

The FES system consists of a multi-channel stimulator with the capability of generating pulse durations up to 150 microseconds and frequencies up to 50 Hz, percutaneous intramuscular electrodes and a four-button key pad worn on the index finger and activated by the thumb. The stimulator is worn around the waist with cables positioned underneath clothing to connect to the electrodes exiting from the anterior thighs. A molded shoe insert is worn to provide ankle and foot protection. Following implantation of percutaneous intramuscular electrodes into the muscles required for upright mobility (Table 1), a four week program of stimulated exercise is initiated to reverse the effects of disuse atrophy. Once the muscles are conditioned, stimulated mobility patterns are programmed and participants are trained in the donning and doffing, operation and care of the percutaneous FES system. During the same time period, each participant is also fitted with and trained

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in the donning and doffing of KAFOs. With FES and KAFOs, a walker, loftstrand crutches or a large suction-cup handle are used to provide balance support during standing and mobility.

Table 1. The muscles implanted with percutaneous intramuscular electrodes.

Muscle	Rationale for Implantation
Vastus Lateralis	stabilizes knee in extension without causing hip flexion
Vastus Medialis	
Gluteus Maximus	provides hip extension
Gluteus Medius	stabilizes pelvis laterally
Adductor Magnus (posterior fibers)	assists in maximizing hip extension in stance
Tibialis Anterior	assists with foot clearance during maneuvering
Adductor Longus	positions legs for sit to stand
Iliopsoas	provides hip flexion for stepping

FES and KAFO Training

Training in FES and KAFOs progresses from static standing in the parallel bars to training in the activities described in Table 2. Starting with the easiest activity, research subjects are trained in each mobility activity with FES and with KAFOs until they reach their highest level of independence; "highest level of independence" is defined as the ability to complete an activity with the least amount of assistance in a timely and safe manner. When the highest level of independence is achieved for the first activity, data are collected with FES and with KAFOs on that activity and training in the next activity is initiated. This process continues until data are collected with FES and with KAFOs on each mobility activity.

Data Collection

An ordinal scale ranging from 1 to 7 is applied to measure the level of independence. A score of 1 represents complete dependence and 7 independence without the need for FES or KAFOs. During each mobility activity, the amount of time taken to perform the activity is also documented. Five repeated measures of independence and time are obtained for each mobility activity with FES and with KAFOs. Each data collection session is videotaped and reviewed to confirm measures.

Data Analysis

The median of the five independence scores and the mean of the five time scores are calculated. A t-test is applied to the time scores to determine if there is a significant difference between FES and KAFO performance.

Table 2. Abbreviated Description of Mobility Activities Used to Compare FES to KAFOs. Activities are listed from easiest to most difficult.

ACTIVITY	DESCRIPTION
Donning mobility equipment	Don all equipment needed for mobility
Level transfer	Transfer to a 20" high mat
Reaching high object	Reach a 16-oz can from a 5'6"-high shelf
Level ambulation	Travel six meters
Up from the floor	Assume stance from floor
Jeep transfer	Transfer into the passenger seat 35" high
Maneuvering	Transfer into an inaccessible bathroom stall
Stair ascent	Ascend 9 steps

RESULTS

Table 3 summarizes the results of the first research subject. As shown, in four of the eight activities, the participant was independent (6) using FES and KAFOs. For the jeep transfer and ascending stairs, FES and KAFOs required supervision (5) and minimal assistance (4) respectively. For the "up from floor" activity, a minimal assist (4) was required with KAFOs; stance was achieved by assuming a prone position and using crutches to toggle into a standing position. With FES, "up from floor" was attempted by first assuming a squat position with the knees tucked; stimulation to the adductor longus assisted in maintaining the tucked position. Once positioned, stimulation was delivered to the vastus lateralis and medialis, gluteus maximus and medius and the adductor magnus and, simultaneously, the subject pulled to stand using a walker. A

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combination of inadequate stimulated strength of the vastus lateralis and medialis and the subject's body weight (174lbs) and spasticity contributed to his inability to safely perform the activity (1).

While the level of independence obtained with FES and with KAFOs was comparable, with FES there was a significant decrease in the time required for five of the eight activities. Significant improvements in performance time with FES are denoted in the shaded areas of Table 3.

Table 3. Results of the first subject of five repeated measures in nine activities with FES and with KAFOs. The independence score reflects the median of five repeated measures. The time score reflects the mean of five repeated measures; standard deviation is shown in parenthesis. Significant improvements in timely performance with FES are shaded. *NT= not tested.

	Independence Score		Time in Seconds (SD)	
	KAFOs	FES	KAFOs	FES
Donning	7	7	679.6 (82.4)	396.6 (32.4)
Level Transfer	6	6	161.5 (41.4)	15.3 (4.84)
Up & Reach	6	6	60.9 (9.0)	40.2 (3.9)
Level Ambul.	6	6	45.5 (2.9)	28.5 (6.9)
Jeep Transfer	5	5	172.9 (25.3)	131.3 (13.1)
Up From Floor	4	1	73.8 (10.8)	NT*
Access Bathroom	6	6	125.3 (27.4)	186.1 (28.3)
Ascend Stairs	4	4	326.9 (36.2)	381.4 (38.7)

DISCUSSION

The equivalency of the independence level obtained with FES and KAFOs by the first subject is encouraging. Equally encouraging are the results of the time data. The time required to don the FES system was significantly less than the time required to don KAFOs. This time difference is appreciated since the donning time required of braces contributes to poor use [6, 7]. For children and adolescents, cosmesis is also an important factor in brace use. As documented with the first subject, if FES is less visible than KAFOs, easier to don and provides comparable levels of independence, youngsters may find FES more desirable when performing mobility activities in home and school environments. Additional data are needed to document the advantages of FES.

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ELECTRICAL STIMULATION OF THORACIC INSPIRATORY MUSCLES

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ABSTRACT

Electrical phrenic stimulation has been utilized clinically for over 25 years. However, lack of support from accessory thoracic muscles has limited the technique's usefulness. In an animal model we found that stimulation of intramuscular thoracic electrodes produces chest expansion which supports the diaphragm (Arch Phys Med Rehabil 76:266-271,1995). This study reports on the results obtained in spinal cord injured (SCI) subjects. Pairs of stainless steel electrodes were placed on either side of the sternum in the 3rd intercostal space. Stimulations were performed at the end of a maximal inspiration. In the 7 subjects tested 2 had intrinsic chest expansion and no response to stimulation. Two reported discomfort and the test was terminated. In the remaining 3, stimulation produced inspired volumes of 284 ± 38 ml which represents 57% of their normal tidal volume. We conclude that in selected SCI subjects, thoracic stimulation can support the diaphragm and enlarge tidal volumes.

BACKGROUND

The use of phrenic electrodes to stimulate the diaphragm has successfully maintained resting levels of ventilation in high level SCI subjects (1). However, in these individuals, and in many others with intrinsic diaphragm activation, inspiration is accompanied with chest collapse. This inward thoracic movement produces poor respiratory mechanics, decreases the efficiency of breathing, and overburdens the diaphragm. The lack of any coordinated contractions from supporting accessory muscles has limited the clinical usefulness of electrical induced inspirations.

APPROACH

Thoracic inspiratory muscles do not lend themselves to the techniques currently applied to stimulate the diaphragm. Small diverse nerves to select intercostal muscles precludes the use of phrenic-type electrodes. We found in animal studies that intramuscular electrodes in intercostal regions next to rib margins can selectively activate thoracic muscles which support inspiration (2). The electrodes were close to but not in direct contact with the ventral branches of thoracic nerves serving intercostal muscles. This method may provide a practical, minimally invasive procedure to stimulate accessory respiratory muscles to support the diaphragm.

METHODS

All patients selected had low cervical lesions, were at least 1 year post-injury and medically stable. A spirometry evaluation was performed which included basic lung volumes and capacities. Both upright and supine evaluations were performed. In addition to spirometry, thoracic excursions were monitored by a low resistance respiratory belt placed mid-thorax.

Stimulation was carried out with small needle electrodes (Life Tech Inc) consisting of single strand stainless wire inserted through a 27 gauge needle. The electrode tips have a small hook to maintain their intramuscular placement. The needle containing the electrode was simply pushed through the skin and into the superficial muscle layer. The needle was then removed leaving the electrode in place. Electrodes were placed in the 3rd intercostal space close to the midline. Electrodes placed lower, within the breast tissue, were ineffective and those below the breast did not support inspiration.

Battery powered neuromuscular stimulators set at 35pps, 100μsec pulse duration, 12 mA was delivered bilaterally for a 2 second period at the end of a maximal inspiration. Changes in lung volume and chest excursions were noted before, during and following stimulation.

RESULTS

A total of 7 patients were studied. In 2 patients some chest excursion occurred during spontaneous inspirations. Thoracic stimulation in these individuals at the end of a maximal inspiration did not produce an increase in inspired volume or evidence of chest expansion. In 2 other individuals afferent activity present in the upper chest produced sufficient discomfort during stimulation that the procedure was terminated. In the remaining 3 subjects inspiration was associated with a collapsing chest wall. Stimulation after maximal inspiration produced an additional inspired volume of 284 ± 38 ml (mean ±SEM) and chest movement toward expansion. There were no differences between the upright and supine positions. Spontaneous breathing connected to the spirometer produced an average tidal volume of 501 ± 31 ml. Thus, the stimulated volume represented 57% of the individuals normal tidal volume.

DISCUSSION

This study demonstrates the feasibility of intramuscular electrodes to selectively stimulate thoracic muscles that support inspiration. Upper thoracic intercostals and parasternal muscles shorten during inspiration and are now considered true agonists of inspiration (3). Others have demonstrated that upper thoracic muscles can be stimulated from an electrode placed on the ventral surface of the spinal cord (4). However, along with inspiratory agonists additional muscle groups unrelated to inspiration are stimulated. This lack of specificity may create problems with clinical applications.

Our electrodes appeared to work best when placed in the 3rd intercostal space, although from this location full activation of all potential inspiratory muscles was not possible. Even though the additional volumes induced with stimulation were less than the individual's tidal volume, they still represent a significant assist to the diaphragm. The tidal volumes recorded on the spirometer tracing were larger than expected from this group and may have been influenced by anxious feelings induced by the equipment . Also, the stimulated muscle groups have been inactive for a long period and at least partially atrophied. Strengthening the muscle could lead to a much stronger response and larger inspired volumes. Additional electrode placements and chronic training of specific muscle groups could have dramatic quantitative effects. Thoracic support for diaphragm-driven respiration should provide a more effective capable system which is less prone to fatigue and failure.

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COATING STAINLESS STEEL ELECTRODES WITH IRIDIUM FOR APPLICATIONS IN FUNCTIONAL ELECTRICAL STIMULATION

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ABSTRACT

Iridium coated single strand 316LVM wire was evaluated for corrosion resistance under high charge injection conditions. Both positive- and negative-first charge injection were conducted for test periods of approximately 240 hours. Charge balanced pulsing was conducted at 60 pps with 100 or 200 μs pulse duration. Charge injections densities ranged from 80 to 1280 $\mu C/cm^2$. Electrical transients were periodically obtained to evaluate the stability of the electrode. Optical and scanning electron microscopy evaluation of the electrodes was also conducted. Corrosion was not apparent with any of the injection protocols as viewed with light microscopy. However, scanning electron microscopy revealed some surface disruptions and corrosion at the highest charge injection densities. The results indicate that the iridium coated 316 LVM electrodes can be used with considerably higher charge injection densities than uncoated electrodes.

INTRODUCTION

The longevity of an FES electrode system is a major concern for clinical applications of chronic neural prosthetics (2,3). Depending on the application, the stimulation demands on the implanted electrodes will vary but the overall goal remains the long term avoidance of corrosion and adverse tissue reaction. Stainless steel 316LVM electrodes are commonly used in neuroprosthetic applications due to their general good corrosion resistance, adequate mechanical strength, and ease of manufacturing. As an electrode material, 316LVM stainless steel may be susceptible to pitting corrosion under certain conditions which are initiated by the breakdown of the passivation layer (1,2,5). The maximum limit of safe charge injection is generally reported to be 40 $\mu C/cm^2$ and only with cathodal-first pulsing. However, we have observed tarnishing with balanced wave forms using anodic- and cathodic-first charge injections of 20 $\mu C/cm^2$ after one year of continuous pulsing (4). As a result of the limited availability of high charge injection electrodes for bipolar stimulation, we have evaluated coatings of sputtered iridium films on 316 LVM substrate wires. Results for both anodic- and cathodic-first pulsing over a wide range of charge injection densities are presented for ten days of continuous pulsing. The films were periodically characterized with electrical transients and light and electron microscopy.

METHODS

Wire electrodes of 316 LVM stainless steel (7 mil) were coated with Ir metal by DC magnetron sputtering. A thin film of titanium was sputtered onto the 316 LVM as an adhesion layer prior to iridium deposition. The sputtering was accomplished with a DC argon plasma at a pressure of 10 millitorr for the Ti deposition and 22 millitorr for the Ir deposition. For pulse studies, coated wire was insulated with #20 thermoplastic polyester heat shrink tubing such that the final exposed length was 5 mm.

Electrodes were pulsed in a bicarbon-ate buffered electrolyte solution purged with 5% CO_2/6% O_2 gas to a pH of 7.4 representative of interstitial fluid [1,4,5]. A stimulator was used to control a stimulus pulse amplifier of our own construction that provided square wave pulses. Charge balanced pulses were obtained with a 0.47 μF capacitor in series with the stimulating electrodes. The capacitor was discharged during interpulse periods through a 1.8KΩ shunt resistor across the output of the stimulator. Monophasic anodic- and cathodic-first current pulses were applied in a 3-electrode test cell comprised of the test electrode, a large surface area Pt counter electrode and a saturated calomel referenceelectrode (SCE) in close proximity to the test electrode. Pulsing at each charge injection level was conducted continuously at a rate of 60 pps for 10 days. Different pulse durations were used because of the limited current available from our stimulator. A 100 μs pulse duration was used for charge injection densities of 80, 160 and 320μC/cm^{2}; a 200μs pulse duration was used for 640μC/cm^{2}; and a 400μs pulse duration was used for 1280μC/cm^{2}. A 100 MHz storage oscilloscope with 10 MΩ impedance was used for recording electrical transients as the potential between the test electrode and the SCE electrode. The current was also recorded using a 100 Ω resister in series with the test electrode. The access resistance (Ra) was obtained from the voltage transient by dividing the access voltage (Eacc) by the instantaneous current. During the pulse the maximum excursion potential [Eex] was obtained by subtracting the access voltage (Eacc) from the maximum voltage vs SCE. The commonly used maximum potential (Emax) was obtained by adding the Eex to the interpulse potential [Eipp]. The interpulse potential (Eipp) was measured just prior to the onset of the current pulse. The Eipp values were found to be identical to the electrode potential measured with an electrometry immediately after the pulsing was interrupted. Electrodes were soaked in distilled water to remove salt crystals before evaluation under the light microscope. Scanning electron microscopy (SEM) of the electrode surface was conducted at the end of pulsing. The appearance of the electrodes under light and electron microscopy are described

RESULTS

The electrical transient components, Eacc, Emax and Eipp, indicated a low impedance to charge transfer of the electrode/electrolyte interface and potential excursions. Eacc is the initial electrical transient representing the initial resistance to pulsing (the iR drop). Absolute values of Eacc for both charge injection protocols were less than 2.1 V for 80 μC/cm^{2} charge densities indicating an Ra of less than 84 ohms. Eacc increased to a maximum value of 6.2 V at the highest charge densities of 640- and 1280 μC/cm^{2}; however, Ra values remained low at less than 62 ohms throughout pulsing. Emax is the maximum potential excursion during the pulse. Values of Emax were less than ±0.95 V va SCE for all charge injection densities. In addition, Emax values for each electrode varied little during the 10 days of pulsing. Eipp reflects the open circuit potential of the test material relative to an SCE electrode as well as discharge characteristics of the pulsed electrodes. The open circuit potential before pulsing was positive at approximately 300 mV. Initial Eipp values for both positive and negative charge injection protocols were positive with values less than 0.8 V. However, at the high anodic pulsing of 640μC/cm^{2}, small but negative Eipp voltages wererecorded.

The relatively small voltages recorded for the electrical transients over the 10 days of pulsing were associated with little corrosion of the iridium coating. Before stimulation, electrodes had a shiny surface without surface disruptions. During pulsing observations with light microscopy continued to show a shinney surface except at the highest charge injection of 1280μC/cm^{2} where a single brown spot was observed during the second day of pulsing and remained a small spot during the remaining 8 days of pulsing. At the end of pulsing the electrodes were also observed with SEM. Cathodic- and anodic-first pulsing above 320 μC/cm^{2} revealed surface disruptions that appear to be delamination of the TiIr coating at the Ti/316LVM interface.

DISCUSSION

Our principal finding was that the iridium coated stainless steel electrodes are resistant to corrosion at charge injection densities, as high as 320 μC/cm2 for anodic and cathodic-first pulsing. Active surface disruptions indicating corrosive processes were present at higher charge injection densities. These charge injection densities are much higher than the maximum of 40 μC/cm^{2} for uncoated 316 LVM stainless steel electrodes [1,4]. Access resistances remained low throughout these studies from 40 to 90 ohms. These resistances are much lower than we previously reported for uncoated 316LVM stainless steel wire electrodes [4,5]. The initial access resistance during 10 days of pulsing was 136 ohms and the final resistance was 246. The Emax values are also low for all of the charge injection protocols conducted here. For example, for the iridium electrodes pulsed cathodally at 80 μC/cm^{2}, Emax values ranged from -0.16 to +0.12 V whereas our previous report with stainless steel under similar pulsing conditions had Emax values ranging between -0.36

to -1.73 V [5; note, these values are converted from reported Eex values]. The less negative potential transients reflect the larger and more available charge injection availablewith Ir compared to 316LVM. Iridium as a charge injection site is characterized as having multiple oxidation states suitable for charge transfer.

For charge densities of 320 μC/cm^2 or less, the Eipp remained close to the open-circuit potential of electrodes prior to pulsing, indicating that the discharge of the capacitor during the interpulse period is effectively complete. The unremarkable values of Eipp and the similar open-circuit potential measurement observed when pulsing was interrupted also suggested that no unexpected electrochemical processes are occurring on the electrodes.

The resistance to corrosion and modest potential excursions observed with charge injection may provide important improvements in electrodes for neuroprosthetic applications. These electrodes would appear to be suitable for high charge injection applications as well as bipolar stimulation. Several groups have raised the potential of applying neuroprosthetics for controlling skeletal muscles, autonomic organs and central nervous system stimulation [1,2,3,6], and iridium coated electrodes may help to provide electrodes for these applications.

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A PORTABLE 24 CHANNEL FUNCTIONAL ELECTRICAL STIMULATION SYSTEM FOR UPPER AND LOWER EXTREMITY APPLICATIONS

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ABSTRACT

A 24 channel functional electrical stimulation (FES) system has been developed for use in both upper and lower extremity applications for children and adolescents with spinal cord injury (SCI) or cerebral palsy (CP). The system consists of a PC-based modular stimulator unit and battery pack. The stimulator can process both Hall Effect sensor inputs used to transduce joint position for proportional control of hand and arm movement and force sensing resistors used as foot contact switches during gait. The stimulator produces an asymmetrical, balanced biphasic waveform for intramuscular stimulation. The stimulus period, amplitude and pulse duration can be individually adjusted for each of the 24 channels. The stimulator is programmed from a Pentium-based host computer via a Windows-based interface program.

BACKGROUND

Research in upper and lower extremity functional electrical stimulation (FES) requires a stimulation system that is relatively small, lightweight and simple for the user to operate and yet contains the power and versatility to investigate novel applications of FES. Historically, these two goals have been at odds because it has been difficult to house the necessary computing power within an acceptably sized stimulator for clinical investigation. With the evolution of personal computer (PC) technology, however, PC's can now deliver tremendous computational abilities within a small area which has made them an important component of FES research devices [1-4].

STATEMENT OF PROBLEM

Our laboratory required a FES system that could be used for both upper and lower extremity applications for children and adolescents with spinal cord injury (SCI) or cerebral palsy (CP). The system was required for both laboratory investigation and for use by subjects at home and school. Thus, the system needed to be portable, light, battery-operated and easy to use outside the laboratory.

We also required a FES system with sufficient stimulation channels and programming flexibility so that complex movements such as stepping or arm motion could be developed. In addition, the system had to process user-generated command signals to control either upper or lower extremity stimulated movement. Control of the stimulus period, amplitude, and pulse duration of the stimulus waveform was also required.

RATIONALE

While most FES systems are designed specifically for upper or lower extremity stimulation, our approach was to design one system to support both applications. Our system's control is centered around a single board PC module. There are several advantages to using a PC over custom designed microprocessor circuitry. There is extensive PC software support available. Off-the-shelf PC technology costs less, decreases design time, and increases reliability over custom designed modules. PC technology is relatively inexpensive to service or replace, and conforms to industry standards which allows a system to be upgraded easily.

SYSTEM DESIGN

A block diagram of the system design is shown in Figure 1. A 24 channel portable stimulator unit was designed to process user-generated command signals and, based on that input, output pre-programmed patterns of stimulation. The unit is programmed via a host computer and is operated as a stand alone system. The following paragraphs describe the major system components.

Host Computer

A Pentium-based host computer is used to control the stimulator during electrode characterization sessions and to develop the stimulation patterns and download them to the portable stimulator unit via serial port communication. The interface program is Windows-based, written in C⁺⁺ programming language and is

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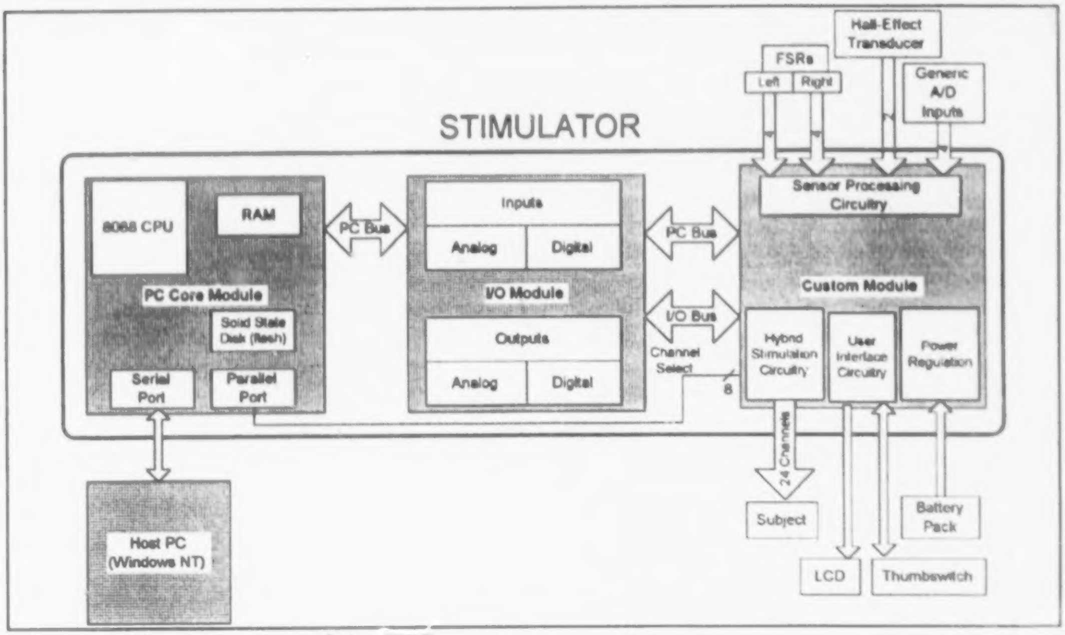
Hall-Effect Transducer
FSRs
Left
Right
Generic A/D Inputs
STIMULATOR
8088 CPU
RAM
PC Bus
Inputs
Analog
Digital
PC Bus
Sensor Processing Circuitry
PC Core Module
I/O Module
Custom Module
Solid State Disk (flash)
Outputs
I/O Bus
Channel Select
Hybrid Stimulation Circuitry
User Interface Circuitry
Power Regulation
Serial Port
Parallel Port
Analog
Digital
8
24 Channels
Subject
Battery Pack
Host PC (Windows NT)
LCD
Thumbswitch

Figure 1: Block diagram of the FES system.

operated in a Windows NT environment.

Stimulator Unit

The unit consists of three modules - an off-the-shelf PC computer board based on PC/104 standards; a custom-designed board that contains the circuits that process sensor signals, produce the stimulation waveforms and regulate power; and an off-the-shelf analog and digital input-output board that coordinates information flow between the two other boards. The unit is 4.5"L x 4.5"W x 2.5"H and weighs approximately 1 pound.

A hybrid circuit chip located on the custom module contains the circuitry to generate the stimulus waveforms for intramuscular stimulation. The circuit generates an asymmetrical, balanced biphasic waveform that can be programmed to provide amplitudes of up to 20 mA in 1 mA increments, stimulus periods from 0-33 milliseconds in 1 millisecond increments and pulse durations from 0-255 microseconds with a 1 microsecond resolution. All three parameters can be programmed independently for each channel.

Thumb Switch

When the stimulator is operated as a stand alone unit, a thumb switch is used to navigate a menu system shown on a liquid crystal display on the stimulator. The thumb switch consists of a four button keypad with two light emitting diodes (LEDs) mounted on a plastic ring that is physically connected to the stimulator via a standard phone cord. The ring slides over the index finger so that the keys can be activated with the thumb. The thumb switch is typically used by a subject to chose and initiate stimulation patterns for standing and stepping. The LEDs relay system status to the user. A hidden menu that can be accessed only by the researcher is also manipulated via the thumb switch for minor adjustments to stimulation patterns.

Control Sensors

The stimulator is designed to interpret signals from two types of sensors: a dual axis Hall Effect joint position transducer used for proportional control of stimulated hand and arm movement; and up to eight force sensing resistors (FSRs) which are typically placed in the soles of the shoes to determine foot-to-floor contact to coordinate stimulation for stepping. Four unassigned buffered, unity gain analog-to-digital (A/D) inputs are available to accept pre-processed analog signals. These are designed to investigate other control sources such as electrogoniometers, electromyography or accelerometers.

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Battery Pack

The battery pack provides power for the system. It consists of 8 4/3 A size nickel metal hydride cells arranged in a 5.75"L x 3.6'W x 1.1"H enclosure and weighs 1.2 pounds. A cable with interlocking connectors on both ends couples the battery pack to the stimulator. A charger allows the batteries to be recharged from a standard 120V electrical outlet. The stimulator can operate for approximately 7 hours from fully charged batteries. Recharging the batteries requires about 5 hours. Because the battery packs are modular, they can be rotated so that one can be used while another is charging. In this way, stimulator down time is eliminated.

EVALUATION

This FES system is planned to be used to investigate the following FES applications for children and adolescents: arm and hand function for those with C3, C4, or C5 SCI; upright mobility for complete thoracic level SCI; and ambulation for those with incomplete SCI or spastic CP.

DISCUSSION

Our research laboratory has developed a 24 channel portable FES system for upper and lower extremity pediatric applications in SCI and CP. It's PC-based, modular design satisfies our need for both a small, lightweight, battery-powered unit that can be used by children in their home environments and a versatile, powerful research stimulator.

For investigations with children, size and simplicity of operation are major concerns. Our device weighs slightly more than 2 pounds which is evenly distributed between the stimulator and modular battery pack. Both units are relatively small. Hence, the system should not burden the child while ambulating using FES. Since we have successfully used the Hall Effect transducer [5], thumb switch [6] and FSRs as control sources in the past with children and adolescents, we feel that control of the system for both applications is sufficiently simple and effective.

For research purposes, a versatile system is important. With our system, the PC module can be replaced with a faster, more efficient module such as a 386 or 486-based computer without modification to the stimulator unit. This would allow us to investigate real time closed loop control schemes. With the unassigned A/D inputs the system can accommodate new control signals. Because the custom board that produces the stimulus waveforms is modular, it can be replaced or modified with circuitry to produce, under the same PC platform, either surface stimulation waveforms or a telemetric signal to control an implanted stimulator. The Windows-based interface program on the host computer provides a user-friendly environment in which to develop complex stimulation patterns and control schemes. This is important for our laboratory since development is performed by both the therapist and engineer.

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A DEVELOPMENT SYSTEM TO ENHANCE FES LEG CYCLE ERGOMETER TECHNOLOGY

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ABSTRACT

A development system was constructed to enhance performance of individuals with spinal cord injury (SCI) for functional electrical stimulation (FES) leg cycle ergometer (LCE) exercise. This development system readily permits changes in FES parameters to optimize recruitment of paralyzed muscle fibers and in pedal load resistance to enable use of various exercise testing and training protocols. For initial testing on the model ERGYS FES-LCE, max current limit was increased from 140 mA to as high as 300 mA, the shank muscles were added to the quadriceps, hamstring and gluteal muscle groups, and the FES firing angle ranges were increased by 55°. Eight subjects with SCI participated in stress testing with the original and the enhanced FES-LCE, using a continuous, progressive intensity protocol. The enhanced FES-LCE elicited significantly higher ($p<.05$) peak metabolic rate, pulmonary ventilation, heart rate, stroke volume, cardiac output and blood lactate concentration. Therefore, the enhanced FES-LCE may permit more effective muscular and cardiopulmonary training capability.

INTRODUCTION

The Therapeutic Alliances, Inc. model ERGYS FES-LCE was designed to promote cardiopulmonary fitness in individuals with paraplegia and quadriplegia due to SCI through leg pedaling via rhythmic induced contractions of the paralyzed quadriceps, hamstring and gluteal muscle groups. A ROM based computer-stimulator system controls both the FES parameters (i.e., waveform, firing angle ranges, current limit) to generate pedaling at 50 rpm and the flywheel resistive load for setting exercise intensity. Although this original FES-LCE technology, which became commercially available in 1984, has been shown to be efficacious (1,2), subsequent research indicated that higher magnitudes of metabolic and cardiopulmonary responses can be obtained via greater recruitment of muscle fibers by increasing maximal FES current (3), and by the addition of the tibialis anterior and gastrocsoleus muscles (4). In addition, a biomechanical modeling technique predicted that FES firing angle ranges could be substantially widened from those originally used to increase the contraction duty cycle for enhancing responses and providing for a smoother and more continuous propulsive action (5). Exercise testing and training responses may also be augmented by incorporating protocols that require the flywheel resistive load to be immediately adjustable in small increments without the need to discontinue exercise to reprogram the system.

Therefore, it would be desirable to have a development system to readily test the effects of altering FES parameters on metabolic and cardiopulmonary responses. In addition, the effectiveness of various exercise testing and training protocols could be evaluated by being able to immediately and continuously adjust flywheel resistive load. Therefore, the purpose of this project was to design and construct a development system that can be used in conjunction with an ERGYS FES-LCE.

METHODS

FES-LCE Development System. Fig. 1 illustrates the FES-LCE development system which can boost max FES current output from 140 mA up to 300 mA, utilize additional muscle groups, vary FES firing angle ranges (via ROM chips), and vary exercise load resistance in small increments before and during exercise. Also illustrated is the instrumentation for monitoring metabolic and cardiopulmonary responses of subjects during FES-LCE exercise.

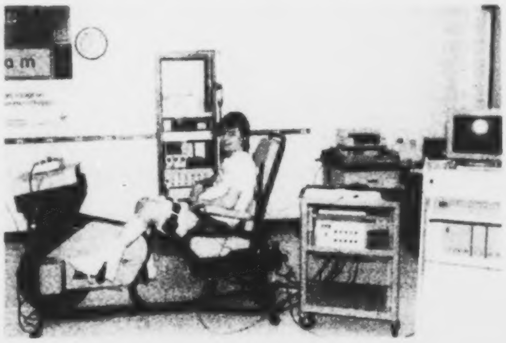

Fig. 1. Illustration of the FES-LCE development system and instrumentation for physiologic data monitoring.

Fig. 2 provides a block diagram of the 10-channel current controller that retrofits to the ERGYS. This component essentially receives the 6 channels of FES output from the ERGYS and provides 10 channels of FES output. The additional 4 channels

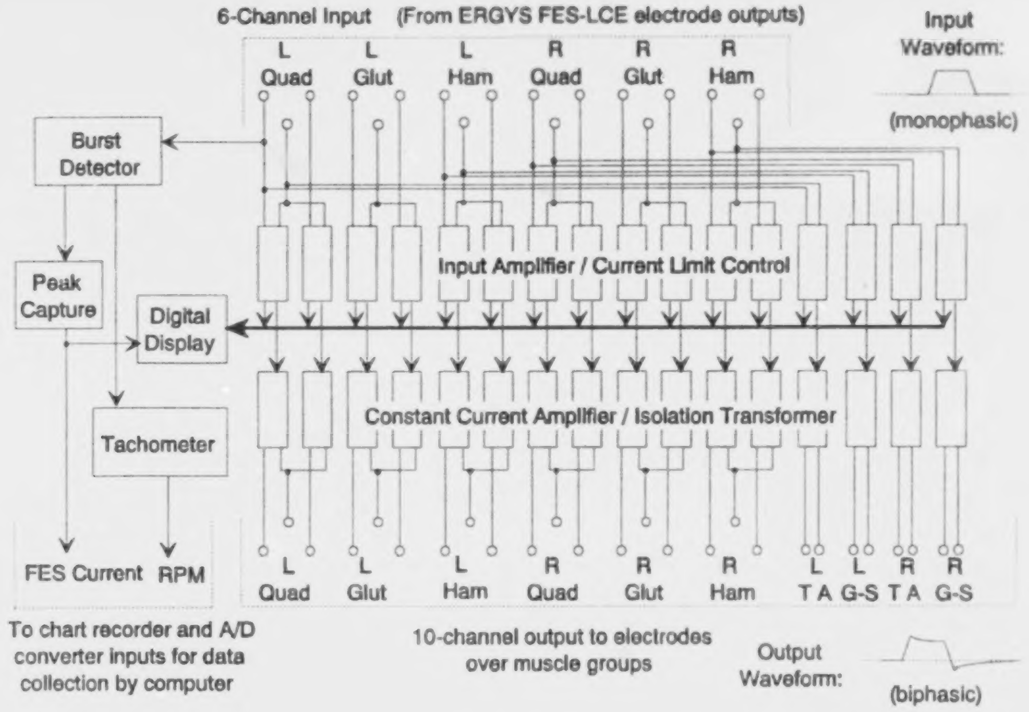
6-Channel Input (From ERGYS FES-LCE electrode outputs)
L Quad
L Glut
L Ham
R Quad
R Glut
R Ham
Input Waveform:
(monophasic)
Burst Detector
Peak Capture
Digital Display
Tachometer
Input Amplifier / Current Limit Control
Constant Current Amplifier / Isolation Transformer
FES Current
RPM
To chart recorder and A/D converter inputs for data collection by computer
L Quad
L Glut
L Ham
R Quad
R Glut
R Ham
L TA
L G-S
R TA
R G-S
10-channel output to electrodes over muscle groups
Output Waveform:
(biphasic)

Figure 2. Block diagram of the retrofit 10-channel current controller for the FES-LCE development system. The FES current for each input channel from the ERGYS FES-LCE is fed to the input amplifier/current limit control, where each signal is scaled to range from zero to the maximum current limit as set by a front panel control. There is an individual current limit control for each of the 10 output channels. Each signal is then fed to the constant current amplifier, where the signal is boosted to the level defined by the front panel control setting (up to 300 mA). The burst detector, peak capture, and tachometer provide the data output for recording the FES current level and pedaling RPM signals for data collection purposes.

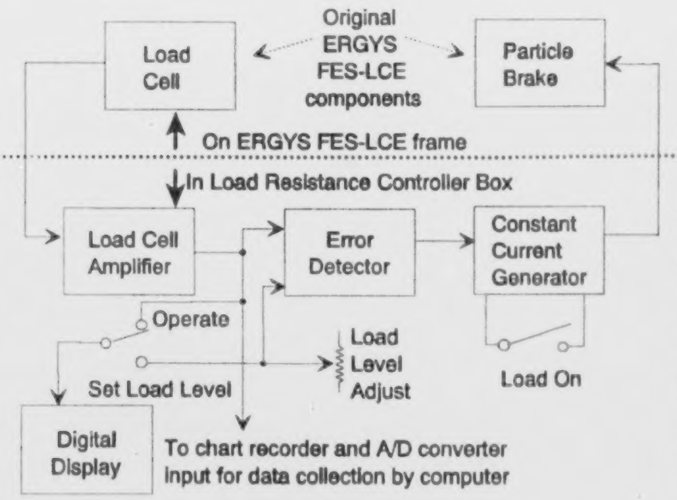
Load Cell
Original ERGYS FES-LCE components
Particle Brake
On ERGYS FES-LCE frame
In Load Resistance Controller Box
Load Cell Amplifier
Error Detector
Constant Current Generator
Operate
Set Load Level
Load Level Adjust
Load On
Digital Display
To chart recorder and A/D converter input for data collection by computer

Figure 3. Block diagram of the retrofit load resistance controller for the FES-LCE development system. The ERGYS load cell/amplifier combination yields a DC voltage output that is proportional to the load resistance applied to the LCE flywheel. This signal is used for data collection. It is also used, in conjunction with thesignal from the load level adjustment control, and with the error detector and constant current generator to regulate the current to the particle brake in such a manner that the load resistance value can be selected from the front panel. Note that this adjustment can be made before, or during an exercise bout.

of FES are used to activate the right and left tibialis anterior and gastroc-soleus muscles. FES to these muscles is configured so that they will co-contract with the right and left quadriceps and hamstring muscles, respectively. The current controller can amplify the FES current to each muscle from a maximum limit of about 140 mA (monophasic pulses) to 300 mA (biphasic pulses). A separate front panel control permits setting of current limit for each muscle before and during exercise bouts. Data outputs are provided for FES current applied to each muscle and the pedaling RPM. Firing angle ranges are adjusted by means of custom ROM chips that plug directly into the ERGYS.

The retrofit load resistance controller for the ERGYS (Fig. 3) incorporates the original ERGYS load cell and particle brake to provide a continuous and immediate setting of flywheel braking force by the turn of a dial. This eliminated the need to discontinue exercise to reprogram the load setting. Load resistance can thus be varied at will during continuous or intermittent exercise protocols.

FES-LCE Exercise Performance. To evaluate the FES-LCE development system, 8 men with SCI volunteered to participate in stress testing on the original and enhanced ERGYS. Subjects were medically screened and signed an IRB-approved consent form prior to participation. ERGYS enhancements consisted of increasing FES current limit to 300 mA, adding the shank muscles, and increasing FES firing angle ranges by 55°. A continuous, progressive intensity exercise protocol was designed to determine peak metabolic and cardiopulmonary responses for both the original and the enhanced FES-LCE. For this, exercise was initiated at 0 kp load, and resistance was increased every 2 min by 1/16 kp (3.1 W at 50 rpm) increments until pedaling velocity dropped from 50 to below 35 rpm, at which time exercise was terminated.

During exercise, expired gases were collected by a metabolic cart, and maximal values for aerobic metabolic rate and pulmonary ventilation (V_E) were determined. Heart rate (HR) was continuously monitored via ECG signals. Immediately after exercise cessation, cardiac output ($\dot{Q}$) was non-invasively assessed by impedance cardiography. Five minutes after exercise a finger tip blood sample was analyzed for blood lactate concentration to estimate the anaerobic energy supplementation.

RESULTS AND DISCUSSION

When comparing exercise performance on the original vs enhanced ERGYS FES-LCE, we found that max PO achieved was similar (mean±SD = 8.6±8.5 W vs 8.2±5.3 W). Lack of greater PO for the enhanced ERGYS was probably due to the fatiguing effects of the longer contraction duty cycle with wider firing angle ranges. However, the enhanced ERGYS elicited higher ($p<.05$) peak aerobic metabolic rate (3.5±0.8 vs 4.4±0.7 METS), V_E (26.7±10.8 vs 38.3±10.8 L/min), HR (76±19 vs 95±10 beats/min), $\dot{Q}$ (5.8±2.0 vs 7.9±2.8 L/min), and LA (4.4±2.1 vs 7.0±1.6 mmol/L). Greater peak metabolic and cardiopulmonary responses obtained with the incorporated modifications to the FES-LCE were most likely due to the recruitment of additional muscle fibers. This may provide greater "overload" to better elicit muscle and cardiopulmonary system training adaptations. In a practical sense, however, this recruitment should be gradually implemented during exercise training programs so as not to cause the early onset of fatigue and reduce potential training effects.

Conclusion. The described retrofit ERGYS FES-LCE development system can permit study of various FES parameters to optimize exercise performance and metabolic and cardiopulmonary responses. The preliminary results obtained suggest that FES-LCE technology can be markedly improved to promote higher levels of health, fitness and rehabilitation potential in individuals with SCI.

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Control of Neuralprostheses I: Sensor Fusion

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BACKGROUND

Preliminary results suggest new possibilities for extracting information from sensors for use in various components of the neuroprosthetic system including:

- Interpretation of user commands and detection of user intentions.
- Discrimination locomotor events and phases see RESNA 96 abstract by Williamson et al..
- Feedback data for control loops; data for hand crafted rule based controllers.
- Data for self-adaptive controllers see companion RESNA 96 abstract by Thrasher et al..
- Data for system diagnostics.
- Patient compliance and functional outcomes.
- Supplementary sensory feedback to the user.

In general, sensors signals in a neuralprosthesis may be considered as windows to the patients neuro-musculo-skeletal system in which inadequate motion is being assisted by FES and unwanted muscle actions (due to spasticity, clonus) may be inhibited by nerve blocking. Each individual sensor is limited in what it can sense and the information it can provide. This can be thought of as a decomposition of the whole neuro-musculo-skeletal status information into its components by the sensors. In the field of pattern recognition and decision theory this is termed sensor (caused) fission [1]. The information fragmentation resulting from this unavoidable fission process can be partially reconstructed by a sensor (information) fusion process.

Here we present preliminary data on sensor fusion based on supervised machine learning to obtain a comprehensive set of signals for neuroprosthetic control from a suite of unobtrusive and reliable sensors. This modular sensor system is being developed for lower limb application in particular, a hybrid FES system to assist paraplegic mobility and extend wheelchair access i.e. transfers, standing, obstacle negotiation and short range locomotion. The hybrid system comprises sensors, control computers, a 22 channel implanted and an ankle foot orthoses [2].

OBJECTIVE

Can machine learning technology be used to map a suite of sensors to a comprehensive set of biomechanical variables required for control of neuralprostheses?

METHODS

Multi-Sensor Suite The sensor suite was chosen heuristically on the basis of minimizing encumbrance; availability of miniature, robust and low cost sensors; cosmesis reliability and ease of use. A more systematic method of selecting and positioning sensors, referred to as sensor simulation has been previously described [3]. The sensors are restricted to and integrated within the AFO's and a waistband. The sensors presently being investigated are: micro-machined accelerometers with a dc response (type ADXL05, Analog Devices Inc.); strain gauges; a custom electromagnetic position and angle sensor. Accelerometers were selected because they are rich in information on inclination and inertial motion. Strain gauges were selected to provide information on brace loading, in particular, to predict incipient knee buckling [5]. The electromagnetic sensor system was chosen to provide information complementary to the accelerometers.

Four accelerometers are distributed in the waistband and three in each AFO cluster. The strain gauges were bonded to the anterior surface of the AFO's. The electro-magnetic position-angular sensor comprises three 12 kHz transmitters distributed in the waistband and three receivers in each of the AFO clusters. Each transmitter coil is activated in turn and the corresponding signal strengths from each receiver were sampled to provide information on relative angle and position of the motions between the transmitters and receivers. A single multi-core cable was used to connect each AFO sensor cluster to the waistband.

The methods described below do not require precise alignment of the sensors with any anatomical structures and no attempt was made to linearise or calibrate the outputs. The set is overdetermined and may be reduced depending on the FES control tasks e.g. for gait event detection the accelerometers in the AFO are sufficient see the companion paper [4] in these proceedings. In order to illustrate the technique we illustrate the approach with two examples:

1. There is often a requirement to monitor specific biomechanical variables that are not directly sensed. Here we illustrate this with two cases: by extracting the knee angle (typical of a signal used in closed loop control) during the standing up and sitting down into an office chair of an able bodied volunteer; by extracting the forward velocity of the foot (typical of a signal that may be used for biofeedback) of an able bodied individual walking on a powered treadmill.

2. In the hybrid FES system described in [2] the floor reaction orthosis stabilizes the knee without muscle activation provided the ground reaction vector is ahead of the knee joint. This allows the electrical stimulation to be turned off for most of the time thus avoiding FES induced fatigue. However should the vector shift behind the knee the extensor muscles must be immediately activated to avoid collapse [5]. We therefore need a knee buckle indicator or even better, an indicator of incipient buckling so that control action can begin before the knee begins to flex. Here we demonstrate that prediction of knee buckling is possible even without the use of the AFO strain gauges.

Knee angle during sit-stand-sit maneuvers.
In this example the waistband sensors and the right leg AFO sensor cluster were used. A reference knee angle signal was obtained from a flexible goniometer (Penny & Giles Ltd. UK) attached across the knee. All the signals were sampled at 100Hz. A neural network (employing the delta-bar-delta back-propagation rule, 11 input neurons and 6 hidden neurons) [6] was then trained to map the sensor inputs to the teacher signal from the Penny and Giles Goniometer. The raw sensor signals input to the ANN are shown in figure 1. (only four of the six electromagnetic signals were used - mainly reflecting the saggital motion of the right limb). The attributes input to the ANN were simply the signal amplitudes. After training the knee angle can then be predicted from the ANN as illustrated in figure 2.

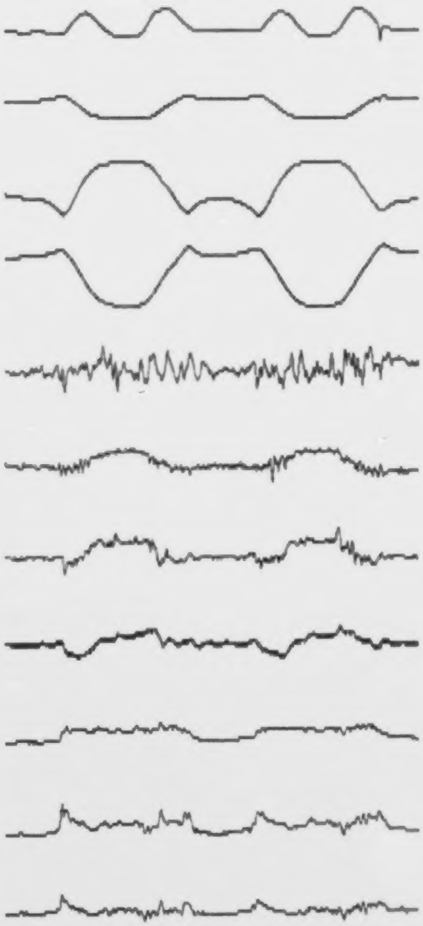

Figure 1. *Typical set of sensor signals. top to bottom: 4 electromagnetic; 4 waistband accelerometers; 3 accelerometers on the right AFO.*

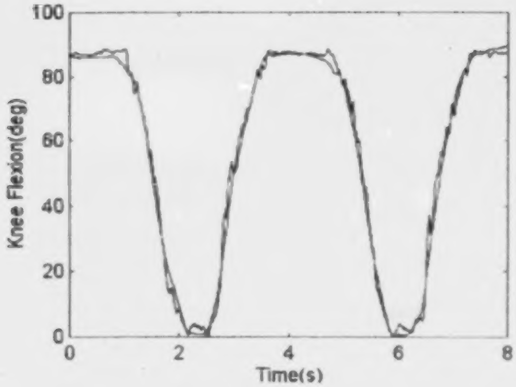

Figure 2. *The predicted knee angle versus that measured by the Penny & Giles goniometer.*

Foot velocity during treadmill walking Here only the accelerometers on the right shank were used as input to a neural network. The derived attributes input to the ANN were; the sensor amplitudes; simple differences; a binary stance/swing signal. The ANN was generated using the Predict algorithm using a Kalman filter [6]. The reference forward velocity data was determined by affixing a retroreflective marker on the foot and measuring its displacement using a TV-computer system. After training the ANN was then able to predict the foot velocity as shown in figure 3.

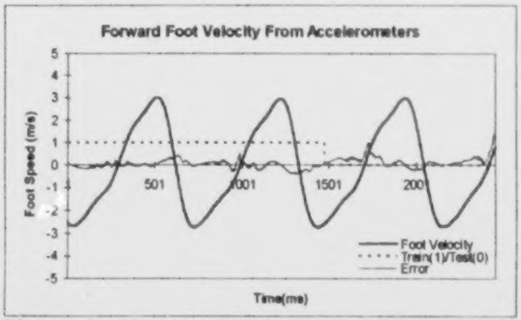

Figure 3. *The predicted foot velocity and the associated error during training and on unseen data.*

Detecting Knee Buckling Here the same sensor set shown in figure 1 was sampled at 100 Hz and input to the Datalogic R rough sets algorithm [7]. Figure 4 shows a typical knee buckle as indicated by the Penny and Giles flexible goniometer signal. The corresponding binary detection signal is shown superimposed.

DISCUSSION

A sensory system for lower limb FES is presented. Sensor fusion techniques using machine learning suggest that a broad range of signals can be extracted from this sensor suit. This means that biomechanical variables can be measured with "virtual sensors" from a sensor suite selected for ergonomic reasons. This technique may have more general application than FES e.g. whenever difficult to measure variables need to be monitored but the application does not allow traditional instruments to be used.

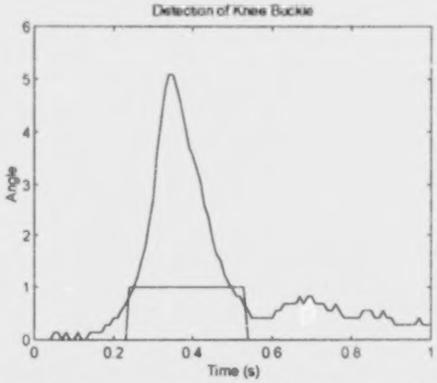

Figure 4. *Knee buckling detector using Rough Sets. The teacher signal, knee angle, as measured by a Penny & Giles flexible goniometer is shown superimposed on the detector output.*

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DIRECT BLADDER STIMULATION IN AN ANIMAL MODEL: EVALUATION OF A NEW SUTURE ELECTRODE

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ABSTRACT

To evaluate optimum methods of direct bladder stimulation, five male cats were instrumented during anesthesia. Multistranded, 316 LVM, stainless-steel, wire "suture" electrodes were implanted on the bladder wall serosa above the trigone area. Additional instrumentation included catheters for pressure recording and electrodes for pelvic floor EMG recording. Studies were conducted in tethered animals following recovery. A second surgery for spinal cord injury (T-1 level complete lesion)was then conducted followed by additional studies. Direct bladder stimulation induced active contractions and voiding both before and after spinal cord injury. Optimum stimulation parameters were similar before and after SCI and consisted of 40 pps, 300 μs to 1 ms, applied for 3 to 4 sec at 10 to 40 mA. The suture electrode did not corrode, erode into the bladder or become dislodged and appears suitable for chronic implantation.

INTRODUCTION

Direct bladder stimulation has been studied in both animals and humans with mixed results. Early clinical studies cited problems including high urethral resistance related to co-activation of striated sphincter mechanisms, poor bladder emptying, the need for high stimulating currents, and activation of lower limb muscles, pain and electrode erosion into the bladder [1]. More recently, Magasi et al., using an improved electrode obtained bladder emptying with stimulation in 29 of 32 patients without significant side effects [2]. The most effective location of the electrodes was adjacent to the ureters where the neurovascular bundle innervates the bladder.

Direct bladder stimulation, however, remains controversial. High urethral resistance with direct bladder stimulation remains a major concern, and concerns with Magasi's work include the large number of electrodes and sutures on the bladder wall, and the lack of long-term results.

We have investigated electrodes for direct bladder stimulation [3]. Current studies involve a suture type electrode that might have the following advantages: (1) an extended length that could be placed across the entire neurovascular bundle that innervates the bladder, (2) implantation in the outer serosal layer that would not erode into the bladder and, (3) a simple electrode requiring little additional implantation procedures such as suturing and which might be implanted through a laparoscope. Studies were conducted in male cats both before and after SCI. Urodynamic responses to stimulation, electrode characteristics, and aspects of this animal model are described.

METHODS

Five male cats (weight 2 to 4 kg) were anesthetized and instrumented with electrodes and pressure recording tubes for subsequent studies using tethered animals. The bladder was surgically exposed via a midline incision, and suture electrodes were implanted on the bladder wall. The suture electrode cable was 50-stranded, 1 mil stainless steel wire (316LVM Cooner Wire Inc., Chatworth, CA) coated with teflon, and the electrode consisted of 7 cm of uninsulated wire. A 21G curved needle was attached to the end for suturing to the bladder wall. Four electrodes were sutured to the base of the bladder. Suturing was started above the ureters and extended downward at an angle toward the bladder neck. The suturing needle was cut off after implanting the electrode. Additional instrumentation consisted of electromyography (EMG) recording hook electrodes adjacent to the urethra. Two small diameter Silastic catheters were also sutured into the dome of the bladder for bladder filling and pressure recording. Abdominal pressure was also recorded. Electrode leads and catheters were tunneled, exteriorized and placed in an animal jacket. Animals were given Oxybutynin following recovery (1.5 mg BID) to increase bladder capacity.

A second survival surgery was conducted for spinalization 4 to 5 weeks after the animal

DIRECT BLADDER STIMULATION

A second survival surgery was conducted for spinalization 4 to 5 weeks after the animal instrumentation. The animals were reanesthetized and the T-1 spinal cord was crushed [3]. The animals were healthy for the 8 to 10 weeks following spinal injury.

Urodynamic studies were conducted with the animals tethered in a urodynamic recording cage both before and after SCI. Pressures, EMG and volume voided were recorded on a strip chart recorder. Cystometry was performed at 5 ml/min, until strong spontaneous bladder contractions occurred producing micturition.

Both bipolar and monopolar stimulation was evaluated in all five animals. For bipolar stimulation, both negative and positive electrodes were on the bladder wall, whereas, for monopolar stimulation the negative electrode was on the bladder wall and the positive electrode was the grounding electrode along the back. Capacitor coupled stimulation was conducted for balanced charge injection pulses with two stimulators (S48, Grass, Quincy, MA). Stimulating parameters evaluated in this study included the period, frequency,current and pulse duration. Stimulation studies were conducted with an initial bladder volume one-half to two-thirds of cystometric capacity.

Additional studies included electrode corrosion and postmortem evaluations. Two bladder wall electrodes were pulsed at the end of the study in a bipolar configuration for 115 hours using 40 pps with 25 mA and 1 ms pulse duration. Following euthanasia, pulsed electrodes and non-implanted electrodes were viewed with light microscopy and with scanning electron microscopy (EIC Laboratories, Norwood MA). Postmortem bladder wall thickness was evaluated after fixation with the installation of 20 ml formalin (HT50 Sigma, St. Louis, MO). Histological sections at the electrode site were stained with H&E.

RESULTS

Five male cats were instrumented before SCI, and urodynamic studies were conducted two to four weeks after surgery when oxybutynine administration had been stopped and bladder capacity had increased. Filling volumes for micturition ranged from 10 to 27 ml. Peak detrusor pressures during voiding were 32 to 75 cm H_2O, and the peak urine flow rates were 0.6 to 2.2 ml/sec. After SCI, an initial cystometry conducted in the second to third week after injury showed numerous small bladder contractions with little voiding. A second cystometry was condicted after five weeks. Stronger bladder contractions occurred, but the bladder contractions were short in duration with little voiding.

Direct bladder stimulation resulted in prolonged bladder contraction and voiding both before and after SCI. Before SCI, peak detrusor responses to stimulation ranged from 22 to 74 cm H_2O. The initial filling volume for these stimulation studies ranged from 5 to 15 ml. The maximum voiding rates were 0.5 to 1.5 ml/sec with a total volume voided with one stimulation period ranging from 5 to 15 ml and with minimal residual volume. The stimulating parameters were 40 pps, 1ms pulse duration, 3 sec train with a current ranging from 7.5 to 40 mA. Stimulation that induced strong bladder contractions in three of the five animals also caused discomfort. However, effective voiding was obtained at lower currents without noticeable discomfort to the animals.

After SCI, three of the cats voided with stimulation in the first two weeks, and two of the cats did not respond to stimulation with voiding until the the third week. Maximal responses and stimulation parameters were similar to before SCI, again the current varied from 7.5 to 40 mA. Filling volumes ranged from 6 to 40 ml. Peak detrusor responses were 22 to 74 cm H20. The maximum voiding rates in response to stimulation 5 to 8 weeks after SCI ranged from 0.1 to 1.8 ml/sec. After 4 to 20 repeated stimulations, three animals completely emptied their bladders, but two animals retained a residual of 6 and 25 ml. These poorer voiding responses at smaller filling volumes may have been due to the shorter duration bladder contractions also seen at these smaller initial volumes. There was no increase in the EMG recorded from the pelvic floor for the five cats immediately following stimulation either before or after SCI. Detrusor pressures were as high as 60 cm H_2O immediately following stimulation without increased urethral resistance indicated by the EMG signal.

Effective direct bladder stimulation techniques were determined. The negative polarity applied to the anterior bladder wall electrodes and the positive polarity to the posterior electrodes was superior in 3 of 5 cats both before and after SCI. This was indicated by higher peak detrusor pressures at lower currents. Stimulation using all four electrodes resulted in higher peak detrusor pressures than any combination of only two electrodes. Also, monopolar electrodes with negative electrodes on the bladder wall and positive electrodes along the back resulted in pain before SCI and increased abdominal skeletal muscle movement after SCI. Subsequent evaluation of stimulating parameters were done using the observed optimum bipolar electrode arrangement with all of the electrodes on the bladder wall.

Fluoroscopic observations of the urethra during spontaneous and stimulation induced voiding was obtained in four of the five animals. During a maximal stimulation at 40 pps for five seconds the entire urethra including the membranous section was seen to open. However, the penile urethra was narrow restricting urine flow. Fluoroscopic observations urethral activity during spontaneous bladder contractions appeared the same as stimulation induced voiding.

Postmortem, mid-bladder-wall thickness was 3.3±1.1 mm for the five animals, and evaluation of the electrodes revealed that they lay in a thin connective sheath in the serosa over the bladder wall. Histological evaluation of electrode sites revealed mature fibrous connective tissue around the electrode in three cats. Smooth muscle submucosal and urothelium under the electrode appeared the same as areas lateral to the electrode site. However, the urothelium and submucosal areas were thickened in all three animals showing inflammatory responses. All of eight electrodes evaluated were shiny based on light microscopy without signs of corrosion after the approximately 14 weeks of implantation and studies described here. In addition, two electrodes were continuously pulsed during the last 4.5 days (115 hours) before sacrificing the animals. Upon harvesting these electrodes, light microscopy observations revealed a shiny surface without loss of metal. However, based on scanning electron microscopy the negative electrode had rare micro pits with little or no evidence of corrosion, whereas the positive electrodes had a few micro pits which were increased in localized areas.

DISCUSSION

The suture electrode appears to be a good design for direct bladder stimulation because the electrodes lay close to the bladder neurovascular bundles yet did not have problems such as erosion, migration, or excessive connective tissue formation limiting bladder filling. Implanting the electrodes with flexing helped to allow for adjustment to bladder filling. This implantation procedure is simpler than previously reported for direct bladder wall electrodes [1,2]. Since all of our electrodes were observed to lie in the outer serosa lining, erosion was not a problem in this animal model. An additional advantage of the suture electrode is that it extends over a long length of the bladder wall. This might help to activate the ramified pelvic nerves that innervate the bladder and require fewer electrodes on the bladder wall.

Current results are similar to our previous report using the "woven eye" electrode before SCI in a cat model [3]. For example, we confirm that bipolar stimulation with both electrodes on the bladder wall is more effective than monopolar stimulation with a positive distant electrode under the skin because with monopolar stimulàtion, abdominal contraction and pain was seen before SCI and muscle contraction associated with current spread to the distant electrode after SCI.

Good voiding responses to direct bladder stimulation were seen in this study. We conclude that stimulation before and after SCI did not increase urethral resistance based on the unincreased pelvic floor EMG immediately following the 3 to 4 sec stimulation period and fluoroscopic observa-tions showing an open membranous urethra.

In conclusion, the suture electrode appears to be effective in activating the bladder in an SCI animal model. However, any clinical applications of the suture type electrode should take into consideration the limitation of this animal model. For example, clinical applications of direct bladder stimulation undoubtedly will require procedures to reduce or eliminate high urethral resistance.

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IMPROVING FES-LEG CYCLE ERGOMETER PERFORMANCE IN INDIVIDUALS WHO HAVE PLATEAUED DURING LONG-TERM TRAINING

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ABSTRACT

The purpose of this study was to determine if an interval training program (ITP) with an enhanced functional electrical stimulation leg cycle ergometer (FES-LCE) could increase exercise performance in subjects who had plateaued during long-term training on the original FES-LCE with the standard continuous protocol. Modifications to the FES-LCE included: increased FES current (140 to 300 mA), adding shank muscles, increasing FES firing angle ranges (+55°), and using an external resistance controller for continuous load setting. Four men with spinal cord injury (SCI) who had trained on the original FES-LCE for 6±1 years were trained for 6 weeks (3x/wk) using the enhanced FES-LCE and an ITP. Power output and metabolic rate increased significantly following training. Results of this study showed that a short-term ITP with the enhanced FES-LCE can elicit marked improvements in subjects whose performance has plateaued during training on the original FES-LCE.

BACKGROUND

FES-LCE technology was developed to permit individuals with SCI to pedal via their paralyzed quadriceps, hamstring, and gluteal muscle groups. It has been shown that FES-LCE exercise training can provide physiological and psychological benefits in individuals with SCI (1,2). These benefits may be unattainable with conventional arm exercise modes (3). However, a problem frequently encountered with long-term FES-LCE therapy relates to the person's inability to exercise at sufficiently high intensity levels to elicit continuous gains in exercise performance and corresponding cardiopulmonary training adaptations. Typically, individuals initiate training at a power output (PO) of 0 W, progress to 6-12 W after several weeks, and plateau at this level for long periods. This mediocre exercise performance results in limited exercise responses and training effects, which can discourage patients and health care providers from using this therapy.

However, recent research suggests that the efficacy of the original FES-LCE technology may be markedly improved by appropriate modifications of FES parameters and muscle groups activated. For instance, increasing maximal FES current from the original 140 mA to 300 mA resulted in notably improved exercise responses, including significant increases in PO and cardiopulmonary variables (4). It was further shown that augmented metabolic and cardiopulmonary responses could be obtained when the gastroc-soleus and anterior tibialis muscle groups were also incorporated (5). In addition, Schutte *et al.* (6) predicted, based on a biomechanical modeling technique, that FES firing angles ranges could be substantially widened from those originally used to provide a smoother and more continuous propulsive action by increasing the contraction duty cycle. Thus, a training regime using combinations of these modified parameters could provide greater overload capability to enhance muscular and cardiopulmonary adaptations.

The plateau in training effects may also be related to the recommended protocol for FES-LCE training, which requires up to 30 min of continuous exercise at a constant PO level during each session. This protocol does not appear to provide the overload necessary to markedly improve exercise performance. Therefore, it may be desirable to develop an ITP, where each session consists of several bouts of shorter duration but higher intensity.

Therefore, the purpose of this study was to determine if an enhanced FES-LCE, used in conjunction with an ITP, could increase exercise performance in subjects who had plateaued during long-term training on the original FES-LCE.

METHOD

Subjects. Four men with SCI (age 44±14 yr, time since injury 13±8 yr, lesion level C5/6, C6/7, C6/7, T6) who had trained on the original FES-LCE for 6±1 years, volunteered to participate in this study. Subjects were medically screened and signed an IRB-approved consent form prior to participation.

FES Instrumentation. FES-LCE was performed on a modified Therapeutic Alliances, Inc. model ERGYS I. A custom-built 10-channel stimulator system, which had the capability to boost maximal current output (bi-phasic rectangular wave, 300 μs, 35 Hz) from the original 140 mA to 300 mA, was used to stimulate the quadriceps, hamstring, gluteal, gastroc-soleus, and anterior tibialis muscle groups. The gastroc-soleus and anterior tibialis muscles were co-contracted with the hamstrings and the quadriceps, respectively. FES firing angles were widened by 55° from the original ERGYS I using a custom EPROM chip. Max current was set to 300 mA for the gluteal and thigh muscles and 110 mA for the shank muscles. One subject, who had partial sensate skin, could only tolerate up to 180 mA.

An external load controller was designed and constructed that could be set to the desired load resistance (continuously variable) by turning a dial before and *during* exercise. This eliminated the need to discontinue exercise to reset the load.

FES-LCE Exercise Performance. A continuous, progressive intensity exercise protocol was designed to determine peak metabolic and cardiopulmonary responses before (for both the original and enhanced FES-LCE) and after (only the enhanced FES-LCE) the training period. The protocol initiated with exercise at 0 kp, and resistance was increased every 2 min by 1/16 kp (3.1 W at 50 rpm) until pedaling velocity dropped from 50 to below 35 rpm, at which time exercise was terminated.

During exercise, expired gases were collected by a metabolic cart, and maximal values for metabolic rate (METS) and pulmonary ventilation (VE) were determined. Heart rate (HR) was continuously monitored via ECG signals. Immediately after exercise cessation, cardiac output (CO) was noninvasively assessed by impedance cardiography. Five minutes after exercise a finger tip blood sample was analyzed for blood lactate concentration to estimate the anaerobic energy supplementation.

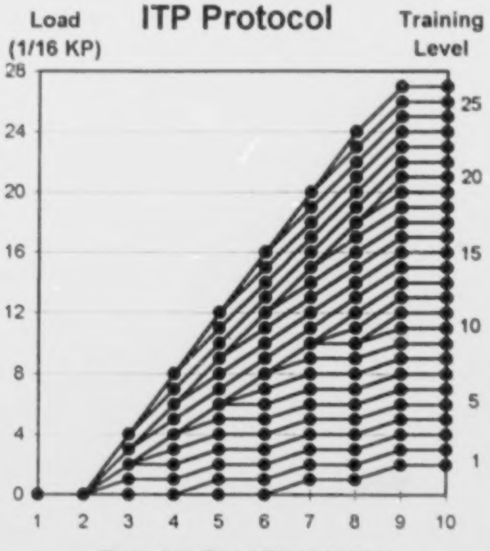

Fig. 1 Schematic description of the ITP protocol.

Interval Training Program. Subjects were trained for 6 weeks (3x/wk) using the enhanced FES-LCE and an ITP. The goal of each training session, consisting of at least 3 exercise bouts, was to achieve 25-30 min of accumulative exercise. Target time for each progressive exercise bout was between 5-10 min. Each bout was followed by a 5-min rest interval. The systematic increase in resistance during the exercise bout at each of 26 training levels is illustrated in Fig. 1. The initial level was established by the pre-training stress test. If subjects exercised between 5-10 min, they started at Level 3, which had the same load progression as the stress test. If they were unable to exercise for 5 min, they started at a lower level; and if they exercised longer than 10 min, they started at a higher level. The level was adjusted each subsequent bout to maintain the 5-10 min target, ensuring continuous overload as exercise capability increased. This pattern was followed throughout the 6-week training period.

RESULTS

The load resistance at which these subjects plateaued while training on the original FES-LCE with the continuous protocol was 0.19±0.07 kp (9.4 W at 50 rpm). During the first training session with the enhanced FES-LCE, the subjects reached load resistance levels of 0.21±0.11 kp (10.5 W), whereas at session 18 load resistance significantly increased to 0.52±0.21 kp (25.8 W). The subject with paraplegia who was used to training on the original FES-LCE at 12.5 W, achieved training levels of 41 W on the enhanced FES-LCE, which is close to the upper limit (44 W) for the original FES-LCE.

Fig. 2 shows the physiologic results of the progressive exercise test before and after the training period. Although PO on the original and enhanced FES-LCE were not significantly different, metabolic and cardiopulmonary responses were markedly higher using the enhanced system. After the training period, PO and metabolic rate were significantly ($p<0.05$) improved. The other variables showed tendencies towards increases, but changes were not significant.

DISCUSSION

The results of this study show that a short-term ITP with the enhanced FES-LCE can elicit significant improvements in exercise performance in subjects whose performance has plateaued during long-term training on the original FES-LCE. The enhanced system clearly increased the the subjects' metabolic and cardiopulmonary response magnitudes, and the ITP appeared to appropriately adjust the load resistance to the progressively increasing exercise capabilities. The perceived increase in exercise intensity was indicated by the subjects by their comments about how much harder they had to work with the enhanced FES-LCE compared to the original FES-LCE. Recovery time needed after the training session was extended accordingly.

Due to the intense exercise and the added activation of the shank muscles vasodilation in the legs appeared to be notably augmented. While essentially no problems in blood pressure regulation were encountered *during* exercise, upon completion of

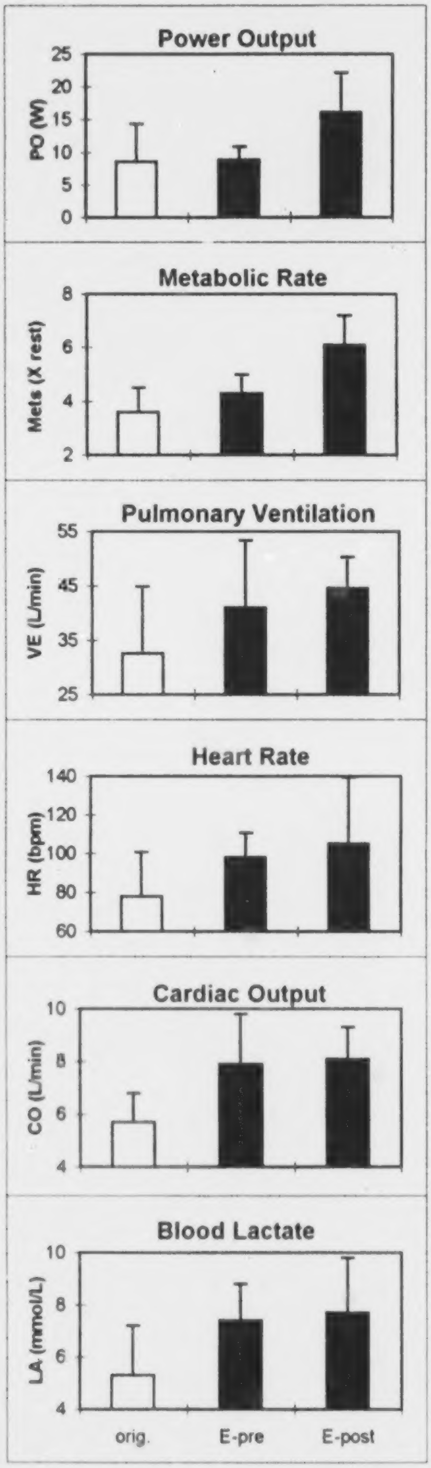

Fig. 2 Exercise responses on the original and on the enhanced FES-LCE before (E-pre) and after (E-post) training.

exercise bouts, lower-limb blood pooling and hypotension occurred in some subjects due to cessation of the skeletal muscle pump. In such cases, the subject was placed in the recumbent position to facilitate venous return and reduce light-headedness. To alleviate this situation, it may be advantageous to continue FES-LCE at zero load during rest intervals to maintain skeletal muscle pump activity.

The lack of a change in CO after the training may be due to a lowering of total peripheral resistance since lower-limb blood vessels were most likely dilated to a greater extent. Longer training periods at the higher PO levels may be required to elicit adaptations for improving this response.

Conclusion. The results of this study suggest that the enhanced FES-LCE, used in conjunction with an appropriate ITP, can be useful to increase the exercise performance of persons who have plateaued on the original ERGYS FES-LCE.

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Control of Neuralprostheses II: Event Detection Using Machine Learning

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ABSTRACT

Machine Learning has been explored as a control method for FES. Modern, micro-machined accelerometers designed for use with airbag control have provided a potential sensor that can be implanted or conveniently mounted on an orthotic brace or belt without the neccesity for precise anatomical allignment. Rough Sets has opened doors for the speed of rule implementation in control systems as well as noise tolerance seen in fuzzy computing methods. Rough sets has shown that it can improve classification of accelerometer pattern in comparison to ALN. The technique of classifying accelerometer pattern with Rough Sets will allow for new control paths in both implant and surface FES.

BACKGROUND

Rule base control of FES has been explored by many. Symons et al. considered a combination of EMG, crutch forces, foot contact patterns, and vetrical acceleration of the thigh for trigger signals in FES [1]. Hip and knee angles combined with foot forces [2] and accelerometers [3] have been used with hand-crafted rules for FES control. Improvements can be made on hand crafted rules by fuzzification and machine learning [4].

Supervised machine learning of rules has also been explored. Rule induction [5], neural networks [6] have been explored as possible FES control methods. Adaptive Logic Nets [7] have shown themselves to be capable of learning a pattern for FES required in a case of hemiplegic gait. Recently, Rough Sets have been shown to be able to discriminate gait phases in normal walking [8]. A comparison between these two methods of learning will provide a basis for continuation of supervised learning methods for control of FES.

An Adaptive Logic Network (ALN) [9], composed of linear threshold units (LTU), AND gates, and OR gates, is a method of piece wise linear fitting a desired output curve from an input pattern. Linear threshold fit data within a particular region of input space and are combined using the AND and OR gates. A decision tree is constructed of the LTU, AND and OR gates.

Rough Sets is purely a classification method. The input space, defined by the attributes, is partitioned into regions in which a minimum percentage of the space is within one output class. Regions of an output class need not only contain examples of that class. This allows for greater rule generalizations and noise tolerance than other rule induction methods.

RESEARCH QUESTIONS

1) Are ALN and/or Rough Sets capable of determining gait phases as from accelerometer data?
2) Which accelerometer attributes are important for gait phases determination?

METHOD

Three +/-5g ADXL05G accelerometers were mounted on a each calf strap. The accelerometers were fixed on surface mount boards provided with the accelerometers and were set up to have a range of +/- 2 g and a 1st order filter at 33 Hz. The accelerometers were sampled using 12 bit A/D at 100 Hz. The arrangement of the accelerometers was not orthogonal, but formed a three dimensional basis.

Interlink force sensing resistors were placed in the insole of the subject's shoe under the heel, lateral metatarsal and medial metatarsal. Gait phases, as described by Perry [10], were determined superficially from the FSRs using the following rules

States	Ipsilateral FSR Readings		
	Heel	Medial M	Lateral M
Loading R	ON		
Mid Stance	ON		
T Stance	OFF		
Pre-Swing	OFF	[ON]	[ON]
Swing	OFF	OFF	OFF
Loading R	[ON]	[ON]	[ON]
Mid Stance	OFF	OFF	OFF
T Stance	OFF	OFF	OFF
Pre-Swing	[ON]	[ON]	[ON]
Swing			

Table 1 *Rules for determination of gait phase from FSR readings*

Experimental data was taken for walking of 5 able-bodied individuals (table 2) around an oval and figure 8 pattern. The oval pattern was approximately 24 m, the figure 8 pattern was approximately 26 m.

Subject	Weight (kg)	Height (cm)	Shoe Size	Figure 8 Speed(m/s)	Oval Speed
A	86	178	9	1.4	1.2
B	66	166	8	1.4	1.3
C	75	176	8	1.2	1.1
D	59	170	8	1.1	1.3
E	66	166	8	N/A	1.1

Table 2 *Physical Characteristics and Walking Speed Subjects*

RESULTS

For each trial a confusion matrix of classification rates was evaluated. The confusion matrix is simply a table that counts what the predicted state is during a sample. A diagonal element of the confusion matrix counts the number of correct predictions of a state. A filter was designed to improve the performance of the classification. It used three future points, enforcing a 3 ms delay in the processing of the data. This delay was not accounted for in processing of data, i.e. the filter results are counted to occur at the time of the sample, the time sample being filtered is not the furthest ahead in time. The filtered confusion matrix diagonals are provided as percentage correct classifications.

The ATREE3.0 program was tested using training files of 15 s with input attributes of the present accelerometer sample, it first past point, and a simple difference of these two values. The training files for the DataLogicR 1.5 program contained the simple difference and two past points. The following table displays the training and testing classification rates for filtered and nonfiltered ATREE3.0 and DataLogicR 1.5 output.

	ATREE 3.0				
Subject	2	3	4	5	6
A	61 (47)	58 (62)	43 (44)	64 (97)	99 (97)
B	58 (29)	63 (61)	38 (50)	87 (66)	93 (92)
C	51 (37)	76 (61)	12 (6)	86 (84)	96 (94)
D	26 (16)	36 (26)	31 (23)	80 (79)	96 (92)
	Rough Sets				
	2	3	4	5	6
A	94(90)	92(88)	69(74)	84(83)	90(78)
B	97(83)	94(81)	98(94)	88(81)	87(83)
C	93(86)	99(97)	0(0)	76(79)	74(71)
D	93(89)	52(22)	99(10)	82(78)	87(77)

Table 3: *Classification rate for gait phases in figure 8 walking of ATREE 3.0 and DataLogicR 1.5. Testing results are in parentheses, training are not*

Rough Sets was also tested on a walking pattern combining figure 8 and oval data. Training files were generated containing 10 seconds of data from each the oval and the figure 8 for one subject. Rules were tested on the remaining data.

	Training				
Subject	2	3	4	5	6
A	87 (96)	86 (92)	57 (58)	76 (80)	95(100)
B	94 (97)	66 (66)	87 (96)	81 (83)	86 (95)
C	84 (86)	90 (96)	11 (8)	91 (92)	79 (82)
D	92 (99)	41 (36)	96(99)	92 (94)	86 (90)
	Testing				
	2	3	4	5	6
A	80 (87)	90 (94)	65 (65)	74 (76)	88 (99)
B	85 (92)	51 (55)	84 (90)	68 (70)	84 (92)
C	70 (98)	62(67)	7 (11)	80 (79)	85 (83)
D	67 (86)	33 (31)	94 (99)	80 (82)	78 (81)

Table 4 *Classification rates for DataLogicR 1.5 trained and tested on both walking patterns. Filtered results are in parentheses, unfiltered are not.*

For practical uses, tests were also run on the rough sets program to determine the importance of the past points and simple difference attributes on the classification rates as well as the importance of each accelerometer.

	Classification Rates				
Subject	2	3	4	5	6
Anterior Only	92.06 (92.25)	88.98 (95.06)	0.00 (0.00)	88.57 (74.06)	92.38 (95.37)
Medial Only	100.0 (96.12)	24.44 (19.71)	0.00 (0.00)	21.37 (0.00)	84.07 (95.48)
Lateral Only	100.0 (98.86)	48.15 (92.35)	0.59 (1.06)	32.86 (10.53)	97.71 (93.25)
Medial& Lateral	100.0 (70.54)	80.25 (46.76)	49.11 (43.27)	35.00 (19.17)	98.93 (85.09)
Lateral& Anterior	98.41 (93.41)	75.06 (66.83)	44.97 (29.82)	87.14 (72.93)	99.09 (94.11)
Medial& Anterior	99.21 (91.47)	91.85 (77.72)	50.24 (44.33)	89.29 (71.05)	97.56 (96.31)
All Accel	97.62 (92.25)	90.62 (81.27)	51.48 (54.09)	90.00 (80.08)	97.41 (87.91)

Table 5 *Importance of accelerometer signals for determination of gait phases. Testing results are in parentheses, training are not.*

	Classification Rates				
Subject	2	3	4	5	6
0 pp	79.08 (74.51)	89.26 (91.61)	46.96 (48.85)	68.71 (61.46)	99.66 (94.96)
1 pp	96.89 (96.89)	65.62 (65.62)	95.67 (95.67)	83.06 (83.06)	95.48 (95.48)
2 pp	86.10 (86.10)	96.59 (96.59)	8.24 (8.24)	91.71 (91.71)	81.73 (81.73)
0 pp, S. diff	97.39 (85.91)	96.29 (98.58)	55.87 (53.96)	92.64 (92.71)	99.83 (88.81)
1 pp, S. diff	99.35 (86.94)	93.71 (95.73)	54.66 (53.96)	75.46 (71.53)	100.00 (89.92)
2 pp, S. diff	99.35 (83.51)	98.47 (99.53)	54.66 (52.94)	75.46 (73.61)	99.31 (87.90)

Table 6 *Importance of past points and simple difference (S. diff) signal for classification rate. Testing results are in parentheses, training are not.*

DISCUSSION

From the above results, DataLogicR 1.5 has shown its ability to classify gait phases from accelerometer signals. DataLogicR 1.5 has also shown a better ability to classify this accelerometer data into gait phases by approximately 10%. DataLogicR 1.5 has eliminated the a disadvantage of inductive learning in comparison to ATREE3.0 by being more noise resilient than previous induction methods.

DataLogicR 1.5 can capably classify data using only a simple difference attribute if three accelerometers are used, and the anterior accelerometer is the most important for phases classification. Improvements in using both DataLogicR 1.5 and ATREE3.0 and the application of heuristic knowledge should provided for better classification results in the future.

As the ALN has previously been shown as a potential controller of FES in hemiplegic gait employing FSR as input signals, accelerometers placed on the shank of the leg and employing Rough Sets as a learning method has control possibilities. Rough Sets has also shown an ability to classify over a more general gait pattern seen in the combination of the figure eight and oval. Error rates of ~20% in generalization seem adequate in an primary trial.

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25 YEARS OF CLINICAL EXPERIENCES IN USING FES BY HEMIPLEGIC PATIENT, PRACTICED IN THE LJUBLJANA REHABILITATION INSTITUTE

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ABSTRACT

25 years overview of clinical experiences using FES in 80% of treated patients with upper motor neuron lesion is given. On the basis of clinical evaluation the most suitable 1-channel, 2-channel and 6-channel stimulator for therapeutic and orthotic treatment were chosen. In recent years dual-channel stimulation of lower and upper extremity has been increased. In spite of technical and medical problems FES beside conventional rehabilitation methods has to be continued following by the biotechnical research.

INTRODUCTION

Electricity as a therapeutic agent was not reported as the use of heat, though the history of electro therapy is a very interesting field. Different devices were used more than a century ago. In 1747 Kratzenstein enabled a learned man, after a single electrification, to play the piano again with his two paralyzed fingers (1). Seiler 1860 reported improvement in cases of scoliosis, while the concept of iontophoresis was first claimed by De Luck in 1908 (1). Since W.T. Liberson 1961 proposed an FES peroneal brace for drop foot correction and L. Vodovnik started in 1965 his own design of the FES peroneal brace, routine application of FES treatment with hemiplegic patients in the Ljubljana Rehabilitation Institute has been introduced. Many different prototypes of stimulators have been researched and evaluated, but only few of them remain applicable for clinical practice. Comparing results obtained by different research centers in the USA and Europe, our experiences are similar (2).

THERAPEUTIC APPROACH

Impaired sensory motor functions in hemiplegic patients (stroke, brain injury, operated brain tumors) are typical persistent sequels after the onset in about 70% of cases. To prevent handicap rehabilitation treatment has to be provided for these patients who are candidates for the FES therapeutic procedure, beside conventional neurotherapeutic treatment. The main goal is to replace the lost central control of movement by artificial FES control, to achieve a functional selective response of stimulated muscle, to break synergistic movement and to reduce spasticity. From the early beginnings on the basis of technological development and evaluation different designs of the 1-channel peroneal brace in routine application are indicated and available in the market. Since the applicability of a 3-channel stimulator reported by Kralj in 1961 (3), few designs of multichannel stimulators with surface electrode have been developed. Finally, a 6-channel microprocessor stimulator for FES in institutional care has been used (4), mainly for research purposes. The results obtained in the research of multichannel electrical stimulation for the initiation of gait by patient with severe impairment have led to a prototype of a dual-channel device (5).

Beside those system surface stimulators, other surface stimulators have been used for the upper extremity stimulation.

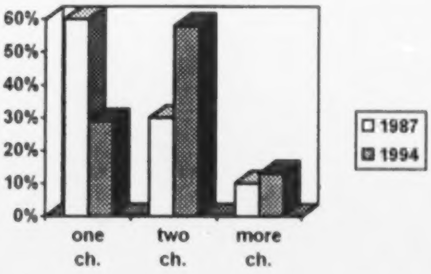
ORTHOTIC APPROACH

Three different types of single channel peroneal surface stimulators, such as also in current use, have distinguishable properties of a typical orthosis. The implantable peroneal underknee stimulator can be excepted, as the most typical orthotic device for the correction of drop foot in patients with an upper motor neuron lesion (6). The dual-channel adapted clinical stimulation system for the control and analysis of gait has been designed in such a way that beside during the therapy it could be used as an orthotic aid. The system consists of two units: stimulator and programmer/stride analyzer. Programmer/stride analyzer is used by therapist for the programming of stimulation parameters in the stimulator unit. The statistical parameters of gait (stride time, left and right stand and swing times, symmetry of gait and number of steps) measured can also be displayed on the programme/stride analyzer (which is a big advantage of the system). Once programmed, the only thing the dual-channel unit requires for operation is turning on and setting the intensities on both channels. This can easily be performed by the patient himself. It enables surface stimulation of two different muscle groups. The stimulation timing can be adjusted for selected muscles and is synchronized automatically with the gait cycle.

RESULTS AND DISCUSSION

Table and Graph 1. Proportion of stroke patients with regard to the number of FES channels applied (over 200 patients per year).

year	1987	1994
one channel	60%	29%
two channels	30%	58%
more ch.	10%	13%



In the recent years the electrical stimulation is being applied in 80% of hospitalized patients and outpatients (7). As initiation of gait and mobility are achieved in a relatively short time (three weeks of radical therapy with a 6-channel stimulator), the hospitalization period is growing shorter (8-10 days) per patient. Due to therapeutic effect the number of channels can be reduced (from 6 to 2 or 1-channel), so the prescription of FES orthoses is on a decrease. The dual channel stimulator and programmer/stride analyzer can be used at home mostly with the help of relatives. Selfmanagement of the system depends on the group of stimulated muscles and upper extremity function. The positioning of surface electrodes to the m. quadriceps and common peroneal nerve is easier than the positioning to the m. gluteus maximus or m. triceps brachii. The first research results in 1993 and 1994 obtained in a group of 1 CP, 11 CVI, 4 TBI patients 568 +- 450 days after the onset, 44 +-13 years of age, showed, that only 8 of them were capable of using the system at home. The same system can also be used for the stimulation of two muscle groups of the upper extremity (agonist - antagonist, deltoid muscle - extensor of the wrist). From Table and Graph 1 increased number of patients treated with the dual-channel stimulator in the year 1994 is evident. After 20 years of clinical experience with the orthotic implantable 1-channel peroneal stimulator, problems on displacement of subcutaneus electrodes due to a fibrous capsule and undesirable not-selective excitation of the deep branch of common peroneal nerve are evident (50 implantations, including 9 reimplantations) (8). The problems of surgical techniques, biocompatible materials, design of a complex nerve electrode and also the problems of surface electrodes have remained the same as before.

CONCLUSION

In our case the first step will be a clinical evaluation of a new generation of simple embodiments of one and dual channel electrical stimulators with electrodes for better selectivity of movement will be done. In spite of many persisting problems the application of FES as an additive method is doubtlessly justified in rehabilitation programs on patients with upper motor lesions. Concerning the long-lasting experiences, technological, biological and biomedical research, especially for implantable systems, has to be carried on. Namely, optimal results can only be obtained by following some general principles developed in practice over the years to comply with patients' and special trained staff's requirements.

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ELECTRICAL STIMULATION FOR FUNCTIONAL LIMB MOVEMENT: SINGLET VERSUS DOUBLET PULSES

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ABSTRACT

If electrical stimulation [ES] is to improve volitional muscle performance or create muscle function for the completely paralyzed, it must produce reasonable force, work and fatigue resistance. For many patients, this must be accomplished in the presence of sensation. Efforts to improve the ratio of force and work production to intensity of stimulation, and to minimize fatigue are important. The purpose of this pilot study was to determine if paired pulses resulted in improved ES muscle performance when compared to the use of single pulses, or singlets. 12 healthy individuals performed a maximum voluntary [MVE] knee extension [KE] fatigue test [40 repetitions, 60 D/sec] and 2 fatigue tests with ES but no volitional effort. Doublet stimulation (closely spaced, 300 uS pulses at the begining of the pulse train) was compared to singlet pulses. Peak KE moment and total work were similar in the two ES trials, but fatigue was less with doublet stimulation ($p<.05$). Maximum comfortable ES produced 18.5% of the subjects' MVE at 60 D/sec.

BACKGROUND

Although it has been demonstrated that electrical stimulation [ES] can be used to train muscle paralyzed by upper motor neuron pathology to produce several hundred functional contractions (ie 40% or more of predicted maximum force output), the ES training protocol is intensive and optimal results are obtained after several months of training [1]. The creation of more favorable force/current or work/current ratios along with improved fatigue resistance is an important goal. This is especially true for the completely paralyzed, neural prosthetic candidate as well as for the patient with muscle weakness whose training protocol may be enhanced by ES.

The force generated during ES of skeletal muscle is related to the intensity of stimulation applied (pulse duration, repetition rate and amplitude). The amount of muscle twitch force produced has been shown to more than double (a nonlinear summation of twitch force) when doublet stimulation (a pair of closely spaced stimulus pulses) was used in place of singlets [2,3]. It also is known that motor units may discharge together normally, ie a doublet, especially in ballistic movement [4]. Karu, et al, have recently demonstrated greater isometric KE torque per pulse with doublet versus singlet stimulation in 27 healthy and 4 spinal injured subjects [5]. A closed-loop,torque tracking design was employed to assess the efficacy of singlet versus doublet pulse trains in generating 15 Nm of isometric KE. Fatigue resistance, indicated by the length of time the target 15 Nm of KE moment could be maintained, was greater with doublet than singlet stimulation. The rate of fatigue increased as the total number of pulses increased [ie triplet versus doublet pulse train]. So, the rate of ES muscle fatigue is related to both the pulse repetition rate [PRR] and the n-let value or number of closely spaced pulses given at a particular PRR [5,6,7].

The purpose of this preliminary project was to determine if the use of doublet stimulation would result in greater knee extension force, work and fatigue resistance during isokinetic ES KE exercise through a functional arc of movement [60 D/sec].

METHODS

Subjects: 12 normal subjects (23.4 ±4.3 years) participated. None of the subjects used ES for regular exercise.

Instrumentation: Cutaneous electrodes (3x4 inch, PALSFLEX, Axelgaard Mfg, Fallbrook, CA) were used for open loop ES exercise (balanced biphasic, 300 uS, 33 pps/with the addition of one paired pulse [1 mS i.p.i.] the onset of the 1.2 second pulse train for doublet). ES was provided by a modular stimulator, plug-in board in an IBM PC/AT. KE exercise was controlled a the LidoActive dynamometer (Loredan Biomedical, Davis, CA). Analog signals from the LidoActive system were sampled by the IBM for angular position, velocity and moment. Calibration, gravity compensation and all data acquisition were performed by the IBM system. An auditory beep (headphones) cued the subject in the voluntary trial. The electrical stimulator was programmed to

CONCLUSION

The greater fatigue resistance observed in the doublet versus singlet ES is in agreement with previous reports [5]. Although the methodology employed in this study did not include a closed loop control design, it does offer a means of documenting repetitive ES quadriceps performance in terms of peak force generation and work. Singlet stimulation resulted in significantly greater fatigue, in terms of force and work production, than doublet stimulation. Doublet stimulation in this study consisted of only one doublet pulse at the beginning of a 1.2 second pulse train, rather than 40 successive doublets [33 pps for 1.2 seconds during KE at 60 Deg/S]. The reduction in the overall number of pulses delivered during N-let stimulation would be expected to yield optimal fatigue resistance when compared to protocols using successive doublets [5].

Enhancement of peak KE moment was not observed with doublet stimulation. It is possible that additional doublets at the beginning of, or interspersed between the pulses in the train would result in greater torque. It remains to be seen, however, if the non-linear summation of twitch force described in isometric contraction will be apparent when muscle shortening is required. Although some subjects volunteered that doublet stimulation was more comfortable than singlet, the intensity of stimulation was similar on the two test days.

It is important to remember that the muscle forces generated in this and prior work [5] are extremely small and would not meet functional KE demands for the completely paralyzed, neural prosthetic user. Patients with Fair [3/5 manual muscle test grade] muscles can move against gravity, but cannot take very much resistance and fatigue is a major problem in daily activities. A Fair muscle can generate approximately 15% of predicted MVC [8]. Fifteen Nm of isometric KE [5] is equivalent to less than 1% of predicted isometric MVC (ranging from 175-400 Nm in healthy young adults). In this isokinetic study, ES produced 18.5% of the subjects MVC at 60 Deg/s. This is still an insufficient contraction if dynamic function is required. If ES muscle forces are to suffice for daily activity, it will be necessary to achieve approximately 40-50% of predicted MVC without significant fatigue for the required number of contractions dictated by the daily activity. The demands are obviously far greater for lower limb, weight bearing muscles than for fine motor control muscles of the upper limb.

Continued assessment of singlet versus n-let stimulation will include: the addition of an isokinetic closed-loop tracking design; an analysis of the effect of increasing the number of doublet or triplet pulses in the pulse train; variance of the spacing between the doublet or triplet pulses; and the inclusion of complete spinal cord injured subjects who have no evidence of present or past denervation in the muscles under study.

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Table. KE muscle performance during 40 repetition exercise test (60 deg/S).

	VOL	SINGLET	DOUBLET	SUMMARY * p<.05, ** p<.01
Peak KE Moment (Nm)	134.2 ±34.9	27.8 ±8.0	24.8 ±9.6	DOUBLET = SINGLET VOL>ES ONLY**
Corrected KE Moment (Nm/weight)	2.21 ±.33	.47 ±.17	.40 ±.17	DOUBLET = SINGLET VOL>ES ONLY **
Work (Nm-deg) 40 reps	3460 ±1076	575 ±212	599 ±330	DOUBLET = SINGLET VOL>ES ONLY **
Corrected Work (Work/weight) 40 reps	57.6 ±15.4	10.2 ±4.0	10.1 ±5.6	DOUBLET = SINGLET VOL>ES ONLY **
% Decrease in KE Moment (Peak to 20th rep)	23.4 ±9.2	37.9 ±13.2	26.8 ±7.9	DOUBLET<SINGLET** VOL SIMILAR TO DOUBLET
% Decrease in KE Moment (Peak to 40th rep)	39.2 ±10.91	47.7 ±13.2	38.3 ±8.0	DOUBLET<SINGLET* VOL SIMILAR TO DOUBLET
% Decrease in Work (40 reps)	39.8 ±9.8	49.2 ±20.1	35.2 ±19.6	DOUBLET<SINGLET* VOL SIMILAR TO DOUBLET

allow the limb to return to 80 degrees of flexion and then immediately stimulate again. No rest interval was allowed between repetitions in either mode of exercise.

Procedure: During each session, a 40 repetition, KE protocol was performed. VOL was performed first and the order of subsequent trials varied. A recruitment curve was performed immediately prior to the ES trials to determine the maximum comfortable stimulus intensity. An electrode placement map assured similar electrode placement on the second ES trial. Peak moment and work performed were documented for each KE repetition and performance data were plotted by a custom software protocol. Statistical analyses were performed with BMDP (p<.05).

RESULTS

Peak KE moment, and peak KE moment corrected by body weight, were similar in doublet and singlet trials [Table]. Work performance, and corrected work, also were similar. Maximum comfortable ES KE moment was only 18.5% of maximum voluntary effort at 60 D/sec. The total work performed during the 40 repetition KE test was not significantly different during the two ES trials, but approximated 17.0% of that done in volitional exercise.

Fatigue resistance, measured by the percent decrement in KE moment and work over the 40 repetitions, was significantly improved in doublet versus singlet ES [Table]. The decrement in moment and work during doublet ES was similar to volitional exercise.

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CUSTOM SILICON CHIP TECHNOLOGY FOR IMPLANTABLE FES MICROSTIMULATORS

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ABSTRACT

A microminiature multichannel implantable stimulator is being developed for the use in therapeutic and functional electrical stimulation (FES) . The stimulation system uses multiple distributed stimulation modules instead of a single unit with multiple electrode leads. Up to 256 implanted modules can be individually programmed for current amplitude and pulse width for each stimulating pulse from a single external transmitter/controller. Initially, the micro-stimulators were designed as one chip devices with one receiving coil and one electrode at each end of a hermetic, biocompatible glass cylinder. However, design and chip manufacturing errors compelled additional components, a diode and a resistor, to be added as off-the-chip parts. Also, the micro-stimulator assembly procedure changed which necessitated transposition of bonding pads on the chip using a process known as gold-bumping.

BACKGROUND

Research by Guyton and Hambrecht (1) demonstrated the biocompatibility of sintered and anodized tantalum as well as the fact that mammalian extracellular liquid can serve as the liquid electrode of a tantalum capacitor. Robblee et al (2) described the ability of activated iridium to pass high current densities without electrochemical side effects. Heetderks (3) in a theoretical study showed the feasibility of an inductively powered implant with a very small receiving coil. As a consequence, the National Institutes of Health initiated a contract that has resulted in development of extremely small implantable and addressable stimulators.

APPROACH

A development of a micro-stimulator with a minimal number of components was proposed: an integrated circuit, a self resonant receiving coil, a protective glass capsule and two stimulating electrodes. One electrode is made of activated iridium, the other is a slug of anodized sintered tantalum. The latter constitutes a wet tantalum capacitor and serves both as a power storage and a charge balance capacitor. The powering and stimulation parameters are supplied by an external, high efficiency class-E transmitter. An amplitude modulated 2 MHz carrier powers and transfers stimulation data to the micro-stimulator and provides the basic clock for the digital part of the micro-stimulator circuitry.

Since the microstimulators are addressable they represent another approach to multichannel stimulation in which each stimulation channel is one stimulator implanted directly at the stimulation site (4,5).

METHODS

An electronic circuit has been designed using a minimal number of components needed to make a implantable stimulator. A single chip circuit was developed that had only four connections: two for the receiving coil, two for the electrodes. The electronic block diagram is shown in Fig.1. The receiving coil continuously charges the tantalum capacitor/electrode through a rectifying diode. The charging current with a sub-threshold amplitude passes through the tissue between the electrodes. At a given command sent from the powering transmitter the charged tantalum capacitor is shorted and releases a stimulation pulse going through the tissue in the opposite direction as the charging current. A number of such commands, sent at a certain rate, generates a stimulation train of pulses.

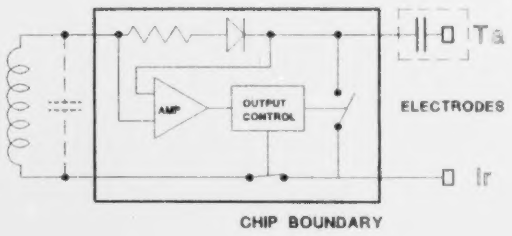

Fig. 1

The rectified RF signal also passes through a series resistor. Any amplitude modulation on the RF signal is observed on this resistor as a voltage variation. By amplifying and cleaning the signal, the information hidden in the amplitude modulation can be extracted.

Typically, the information contains idle pulses, device address (0-255), pulse-width (3.5 μs-257.5 μs in 256 equal steps), current amplitude (0.2 mA-60mA in 32 steps) and capacitor recharge current (10 μA and 100 μA). The maximal stimulation voltage is 7.5 V and the maximal pulse rate is 637 Hz per unit.

Theoretically, 256 individual addresses can be accommodated with the number of bits reserved for addresses. In the chip production, seventeen distinctive chips were designed that differ only in their "address number". Stimulator "address" identifies the stimulation channel.

A 3 micron P-well double poly CMOS technology was selected for the chip development. This technology makes possible combination of analog and digital circuits in the same process on the same chip.

RESULTS

When trying to manufacture a micro-stimulator according to the design, we came across several difficulties. First of all, the silicon chip did not perform according to the design. The on-the-chip rectifying diode had to be bypassed by an external diode. This enabled powering of the device, however the retrieval of stimulation information became less reliable since the series resistor was bypassed with the external diode as well. In spite of that we were able to assemble several tens of microstimulators and test them in vitro and in experimental animals to verify their biocompatibility and functionality. Fig. 2 shows a schematic assembly drawing of such a micro-stimulator. A micro-stimulator is 16 mm long and 2 mm in diameter.

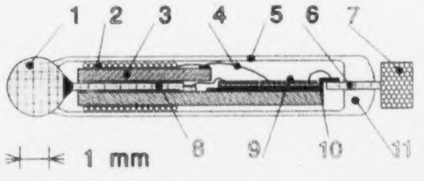

Fig.2 : 1-iridium ball; 2-Coil; 3-Ferrite; 4-Bond wire; 5-Glass tubing; 6-Feed-through; 7-Tantalum electrode; 8-Extension stem; 9-Custom chip and external diode; 10-Metal shim; 11-Glass bead.

To improve the micro-stimulator's reliability, an external resistor was added in series with the external diode which required cutting of the diode connection on the chip itself. A trimming laser was used for this purpose. Because the external diode and resistor could accept only the first bond (ball bond), an intermediate land was created that could accept the second bond, (wedge bond), and thus enable the series connection of the diode and the resistor (Fig.3). Even though the scheme worked very well on a bench, due to inaccurate aim and water vapor ingress into the active silicon through the broken surface chip protection layer, these microstimulators failed to work a few weeks after encapsulation. As it can be seen, the initial idea of having only two components inside the glass capsule is severely compromised. Therefore it was decided to change completely the assembly procedure, fix the errors on the chip and add components which would make the assembly easier and the device more manufacturable.

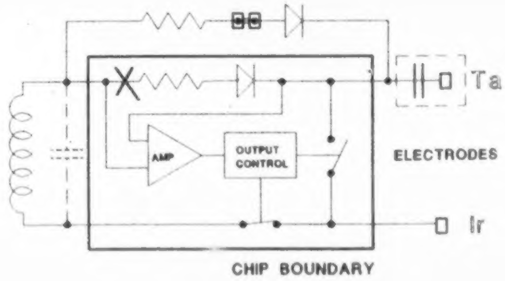

Fig.3

The new chips performed even worse than the first ones, so we returned to the first chip while the problems with the second chip were being identified. We intended to again use the approach with the diode trace cutting and an external diode and resistor configuration. This time, the cut in the chip protective layer would be sealed and protected by a layer of silicon nitride.

The new assembly procedure required all bonding pads to be on one side of the chip and have a certain sequence to make short bonds to the underlying micro PC Board. For that reason the old bonding pads had to be repositioned using a process called gold-bumping.

The gold-bump process can only be done on an uncut wafer and requires several operations, described below. The processed wafer is plasma cleaned and a 10,000 Å thick layer of low temperature silicon nitride is deposited over the wafer. Photo-resist is spun over the nitride and the old bond pads are exposed. The nitride is etched off at the pads and the rest of the photo-resist is washed off. A 2,000 Å thick layer of titanium-tungsten is sputtered on the wafer. It serves as a barrier between aluminum and gold and also promotes gold adhesion. It is followed by a 1,000 Å seed layer of gold. Again the photo-resist is spun on the wafer, its thickness defines the thickness of the future gold traces. The photo-resist is exposed to UV light through a mask showing the traces and subsequently developed. The wafer is plasma etched (few minutes in oxygen or argon) for one more time to remove the remnants of photo-resist. This leaves the seed layer of gold exposed. The gold-bumps are then electroplated on the seed layer to the desired thickness. Then the unexposed photo-resist is removed. The wafer is dipped into an etch solution which removes the layer of titanium- tungsten. Cleaning and rinsing is required at the end of the process.

This time the diode trace was cut manually, using an ultrasonic trace cutter. It took 50 cutting probe tips and two weeks to cut diode traces on more than 1,200 chips on the wafer.

A wafer with gold-bump chips delivered from a vendor was 100% electrically tested. There were 1,003 good chips and 136 bad chips on the wafer, which represents a 88% yield.

Transposition of bonding pads enabled us to use the previously manufactured μPC Board as the μstim chip substrate. To accommodate the additional resistor the conducive areas on the μPC Board were reassigned. This modification required one long bond wire going from the chip pad to a distant conductive area on the μPC board. To stabilize this and other bond wires, a glob top epoxy has to be applied over the exposed chip and bond wire area.

DISCUSSION

Custom made silicon chips with combined analog-digital circuits are expensive to design and manufacture. Very often the first or even the second attempt to make a fully working chip results in a failure. In our case we were dealing with a chip that had a defective diode on board, which made the chip useless. Luckily, the position of the diode in the circuit and physically on the chip was such that it could be effectively removed from the chip and replaced by an external diode. Moreover, the resistor, essential for the data demodulation, was also conveniently placed and could be replaced by an external device. Having two additional devices in a small package required redesign of the package which in turn demanded repositioning of the bonding pads using a relatively inexpensive gold-bumping process.

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SIG-11
Computer Applications

JESTER - A HEAD GESTURE RECOGNITION SYSTEM FOR WINDOWS 95

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ABSTRACT

Gestural interfaces to computers are gaining prominence in the research field of human-computer interaction owing to their intuitiveness and their ability to be tailored to a particular user's capabilities. Gestures form a natural part . of communication and valuable information is contained in them that is currently being neglected in traditional human-computer interfaces. Head gestures can provide a particularly attractive method of computer access for disabled individuals, as people with severe motor disabilities often have a sufficient degree of head control for recognition purposes. This paper describes a PC-based head gesture recognition system that has been designed to be easily incorporated in future software applications. The system runs in the Windows 95 environment, and a commercial version should be available by the end of 1996.

BACKGROUND

Substantial research work has been done in the computer recognition of gestures, using techniques such as hidden Markov models, neural networks, and finite state machines[1][2][3][4]. These procedures have generally been tailored to particular applications, and have not been flexible or easily accommodating to any changes in the user's ability to perform gestures. Research into gesture recognition at this organisation originated in 1986, when Harwin [1] identified head gestures as a possible means of computer access for severely disabled individuals. Harwin designed a number of recognition algorithms based on finite state machines and hidden Markov models, and showed that head gesturing could indeed be used to communicate with computers.

Harwin's original research lead to the authors current work. A head gesture recognition system was designed and built around the following design criteria [5]:

- The system should be simple to use.
- It should be inexpensive.
- It should have the ability to adapt to an improvement or deterioration of the user's ability to perform head gestures.
- Its gesture recognition accuracy should be high.
- The system should be trainable on small amounts of data.
- It should be able to cope with a range of gesture vocabularies.
- It should provide a simple method of incorporation in the development of computer software.

The prototype system was known as the Head Gesture Recognition System (HGRS) [6]. HGRS ran under DOS, and used a commercially available transducer, the Polhemus 3Space Isotrak [7], in order to translate the users movement and position into data understood by the computer. Instead of using recently developed recognition techniques such as hidden Markov models and neural networks, the system used a template based technique known as Dynamic Time Warping which was combined with heuristic rules in order to effectively recognise head gestures. This algorithm, known as the Hybrid Recognition Algorithm, had the advantage of being fast, and could easily be trained with one template per gesture [6].

The recognition performance of HGRS was evaluated by performing a set of user trials. The trials were performed by six subjects who had severe athetosis in their movement. The gesture vocabulary used by the subjects consisted of eight gestures (up, down, left right, yes, no and two custom gestures), and the recognition rate of the system was found to be 85.5% [6].

THE JESTER SYSTEM

The promising recognition results from the DOS based prototype led to the porting of the recognition algorithm to the Windows 95 platform, under the name of Jester. The enhanced display features of a graphical user interface platform enabled the recognition system to acquire a friendlier and more intuitive user interface. In addition, the ability of Windows to link pre-compiled code to applications at run time (through Dynamic Link Libraries, or DLLs), made Windows a suitable environment for developing applications that could use Jester.

Jester consists of a Dynamic Link Library, which can be accessed by an application and deals with all

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aspects of the gesture recognition process. The structure of Jester is described in figure 1.

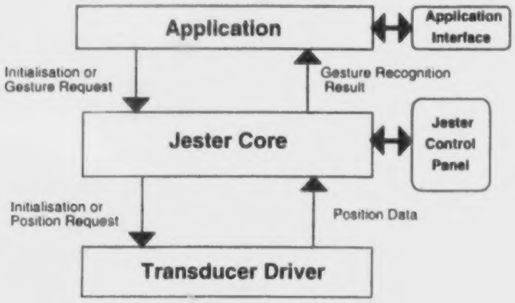

Application
Application Interface
Initialisation or Gesture Request
Gesture Recognition Result
Jester Core
Jester Control Panel
Initialisation or Position Request
Position Data
Transducer Driver

Figure 1: The Structure of Jester

The recognition system consists of two basic components: the Jester Core, and the Jester Transducer Driver. The core handles all recognition tasks in the recognition process from segmenting a gesture to providing the application with a recognition result. The transducer driver deals with the communication to the transducer, and the translation of the raw transducer data into a format that is understood by the Jester Core. The reason for separating these two components in the recognition system is that it is foreseen that a number of transducers will be used with Jester. The type of transducer used will depend on the kind of gestures being recognised, the movement ability of a particular user, and the available finances of the user. Currently, the only restrictions on a transducer are that it must have a maximum of six movement axes, and a minimum sampling rate of 30 samples/second.

As can be seen from figure 1, the interaction between the various layers of the Jester structure, are simple and well defined. The communication between the application and the Jester Core is achieved through the Jester Application Programming Interface (JAPI). This is a collection of C++ functions, such as 'Initialise System' and 'Recognise Gesture', which enable software developers to access the Jester system without requiring any knowledge of its complex internal structure.

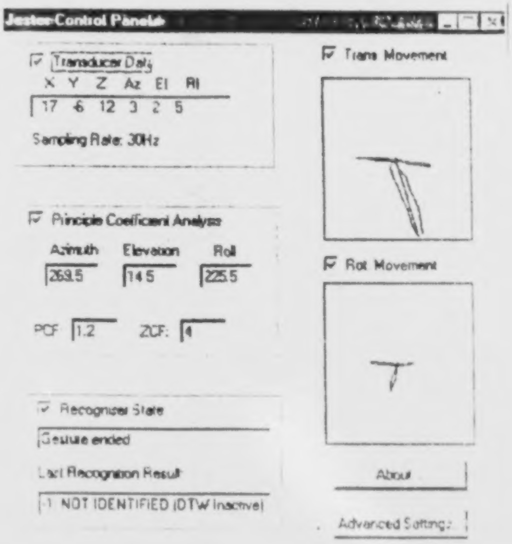
The communication between the transducer driver and the Jester Core is also well defined. In order for a driver to be Jester compatible it must provide a number of functions that Jester can access. These functions perform tasks such as identifying the transducer, initialising it, and retrieving position data. The transducer driver is itself a DLL and can therefore be selected from Jester at runtime.

USING JESTER

Jester needs to be trained to recognise a user's gesturing characteristics before it can be used in an application. In order to simplify the training task, an application called Trainer has been developed. Trainer enables a user or carer to adjust a number of user dependent settings that optimise the system's performance, and to record the gesture templates that the user has chosen for his/her vocabulary.

Once trained, Jester can be used by the particular user in any application that accesses the Jester DLL. During initialisation, the user is requested to enter his or her user ID. This allows the system to be customised to different user templates and characteristics. In addition, the user is able to select the type of transducer that will be used in that session.

As shown in figure 1, Jester has its own interface, in the form of a control panel. The control panel, shown in figure 2 can be used to monitor the user's gesture performance, and also provides an ongoing insight into the state of the recognition algorithm.



☑ Transducer Data

X	Y	Z	Az	El	Rl
17	-6	12	3	2	5

Sampling Rate: 30Hz

☑ Principle Coefficient Analysis

Azimuth	Elevation	Roll
269.5	14.5	225.5

PCF: 1.2
ZCF: 4

☑ Recogniser State
Gesture ended

Last Recognition Result
-1 NOT IDENTIFIED (DTW Inactive)

Figure 2: The Jester Control Panel

An additional function of the control panel is that it enables the user to adjust some of the recogniser's parameters during the course of an application session. This is useful for users whose movement characteristics such as tremor may change frequently enough to affect the recogniser's performance during a session.

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JESTERMOUSE - A MOUSE EMULATOR

Jester is still in the development stage, and there are currently no commercially available applications that support it. In order to provide gestural access to existing Windows applications, a gesture based mouse emulator called JesterMouse was developed. With JesterMouse, a user can access existing applications that have not been designed for use with a head gesture-based input device. This provides an indirect access to applications, and is limited by the functionality of a mouse pointer. In order to exploit gestural access fully however, the inputs provided by the gestures should be directly linked to application tasks. It is expected that a number of Jester compatible applications, as well as Jester based access programs such as keyboard emulators will be developed in the future.

FURTHER WORK

A set of user trials is currently being performed with a beta version of the Jester system. Eight subjects with a range of disabilities are taking part. The aim of these trials is to investigate whether this type of input can be effective in executing computerised tasks. The tasks performed therefore involve accessing existing Windows applications with the help of Jester. In addition, feedback on the design of the system from the users will be used to implement final changes to Jester before its commercial release.

There are two transducer drivers currently available for Jester. The first is a Polhemus driver, which is being used in the current user trials. The second is a joystick driver, which enables gestural input from a PC-compatible analogue joystick. When used with JesterMouse, this driver provides joystick access for the Windows interface. As part of further research, the Jester system will be tested with a range of transducers, in order to examine how well it can cope with movement in a number of different axes. In addition, trials with gestures from different sites of the body, such as hands and arms will be performed.

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POTENTIAL PROBLEMS ASSOCIATED WITH USE OF SPEECH RECOGNITION PRODUCTS

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Abstract

Commercial speech recognition dictation products are increasingly being used as alternate input devices for computers, particularly by persons with physical disabilities. These discrete speech recognition products require the user to insert brief but distinct pauses between each spoken word. The need to isolate each word while dictating text causes the vocal folds of the untrained user to slam open and shut, resulting in glottal attacks. The tendency to maintain constant pitch, volume, and inflection while dictating to the computer results in keeping the musculature in a fixed position. Maintaining this musculature in a rigid position for extended periods of time could eventually result in injury. The growing use of speech recognition products by persons with and without disabilities indicates an urgent need to determine potential problems associated with the use of these products. Preliminary studies indicate that persons with Repetitive Strain Injuries (RSI) may be most vulnerable. Common-sense strategies (take frequent breaks, drink plenty of water) may postpone or minimize problems.

Background

Several powerful speech recognition systems for dictating text to computers are now commercially available. Systems for IBM-compatible computers include DragonDictate from Dragon Systems, Kurzweil Voice from Kurzweil Applied Intelligence, and VoiceType Dictation from IBM; PowerSecretary from Articulate Systems is available for the Macintosh.

Each of these systems has several features in common with the others, including:

- Large vocabulary size — Each system has active vocabulary sizes of 30,000 to 60,000 words, allowing the user to enter text by speaking entire words, rather than entering letters individually.
- Speaker-dependence — The user of each system must train that system to recognize how he or she produces different phonemes.
- Isolated word — Each system requires users to pause between each word so that the speech recognition system can determine the boundaries between utterances before processing the utterance.

Speech recognition systems are popular alternate computer input methods for two principal reasons: speech is a natural form of communication, and speech recognition systems can recognize speech at a rate faster than many persons can type (typically 30 to 50 words per minute (1,2,3)). The fast input rate using speech is especially useful for persons with physical disabilities limiting their ability to operate a computer keyboard.

The sales of speech recognition systems are expected to grow at an annual rate of 26%, with the market for speech-recognition applications reaching $750 million by 1997 (4). This growth is expected partly because of the rapid increase in the incidence of RSI injuries. Occupational and Health Safety (OSHA) statistics for 1992 showed that 56% of all work place injuries during the year were due to RSI, up from 18% in 1981 (5).

Repetitive Stress or Strain Injury (RSI), also known as Cumulative Trauma Disorder (CTD) or Occupational Overuse Syndrome (OOS) can be defined as a physiological condition that develops due to long-term trauma or stress to the body. Repetitive activity of the musculoskeletal system may lead to several symptoms, particularly pain. These symptoms could be attributed to local pathology directly associated with repetitive motion or forceful movements of the musculature, or may be part of referred pain which relates to postural effects (6) . Several factors give rise to RSI, including (a) rapid, repetitive movement, (b) less frequent, more forceful movements, and (c) static load (7).

Some anecdotal evidence of problems believed to be caused by improper use of the discrete speech recognition systems is available (8,9). Persons using the systems have reported severe problems with their voices, such as hoarseness, sore throats, and even a complete loss of their voice.

Research Questions

- What, if any, are the types of problems caused by the improper use of speech recognition products? What are the extent of these problems and their repercussions? What are the initial symptoms that can lead to a clinical prognosis and appropriate intervention? What precautions can be taken by the user in order to avoid or minimize these problems?
- Can certain risk factors be identified? Are risk factors independent of either the technology or the user? Do the studies suggest that certain populations, categorized by physical or psychological differences, are more susceptible to voice problems than others?

Method

Pre-therapy baseline assessments were performed with five 5 clients using Kay Elemetric Computerized Laboratory and Aerophone equipment. These tests include spectrographic, spectral, LTAS waveform, LPC pitch and energy analysis, phonatory air flow studies, and audio tapes.

A survey was posted on the Internet. Respondents were asked to provide brief answers to questions regarding their usage of speech recognition products. They were also requested to indicate if the researchers could make follow-up contacts for more detailed information.

The clients of the UT Rehabilitation Engineering Program who have received speech recognition systems over the last 3 $^{1}/_{2}$ years were contacted to determine what problems, if any, they are having with their systems.

Results

For the five clients tested extensively, the following symptoms were prevalent:

- inappropriate low pitch
- monotone speech
- weak, barely audible voice
- inability to modulate voice
- uncontrollable coughing bouts
- chronic hoarseness
- frequent aphonic episodes

The otolaryngology diagnoses for these individuals are shown in Table 1.

Table 1. Otolaryngology diagnoses of five persons undergoing extensive clinical testing.

diagnosis	# of participants
bowed vocal cords	1
vocal fatigue	2
chronic hoarseness	1
vocal abuse.	1

The participants in the preliminary study included the five individuals who underwent extensive clinical testing, fifteen persons who responded to a survey posted on the Internet, and five persons who responded to a phone survey (a total of twenty-five participants). The responses were categorized into 3 groups: Group A reported no problems with the use of their speech recognition systems; Group B reported the development of problems with their voices; and Group C reported that they had discontinued use of the speech recognition system for reasons other than health. The results of that survey are summarized in Table 2.

Table 2. Summary Results of Preliminary Study on Use of Speech Recognition Products

# of persons	Group A	Group B	Group C
RSI	3	10	0
non-RSI	1	1	3
disability not reported	3	4	0
Totals	7	15	3

Of the twenty-five participants, fifteen claim to have experienced problems with their voices. Three of these individuals reported that they have stopped using speech recognition altogether because of the severity of the problems they experienced with their voice.

A high percentage of participants reporting a disability indicated that their disability is RSI-related (13 out of 17). Three of the four persons in Group A reporting a disability indicated that their disability is RSI-related. Ten of the eleven persons in Group B reporting a disability indicated that the disability is an RSI-related injury.

The persons who experienced problems such as hoarseness, sore throats, etc. reported using the speech recognition systems from 45 minutes to 3 hours at a stretch, without taking breaks.

Discussion

These preliminary results indicate that improper use of these discrete-word speech recognition systems may cause moderate to severe problems in the voices of the users. This initial study also indicates that persons with RSI may be more susceptible to vocal injury. It has been hypothesized that these persons have a tendency to work longer and harder, thereby increasing the probability of stress-related injuries.

Based on preliminary information, the following recommendations (10) may allow users of speech recognition systems to protect their voices:

- Take frequent breaks.
- Perform warm-up and cool-down voice exercises.
- Limit the amount of time using the speech recognition system.
- Drink plenty of water.
- Avoid clearing the throat.

Also, clinical professionals who evaluate others for appropriate assistive technology should consider the recommendation of alternate methods of access in addition to speech recognition. Clinicians may want to avoid the recommendation of speech recognition systems for persons who have a previous history of vocal problems.

A number of questions have not yet been addressed, including the following:

- Would initial training on a speech recognition system by a speech-language pathologist minimize problems?
- Are there psychological or physiological factors that contribute to someone with RSI having a higher probability of incidence of voice problems?

Though extensive use of isolated-word recognition systems may lead to problems with one's voice, upcoming continuos-speech recognition dictation systems will hopefully ameliorate or even eliminate these problems, particularly if the systems are designed to recognize speech with natural inflection patterns.

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THE KEYBOARD CHANNEL AS AN INVISIBLE COMMAND PATH FOR ALTERNATE INPUT DEVICES

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Abstract

A prototype software utility is presented which interprets special "codestrings" in Microsoft Windows 3.1 to control low-level system functions through existing alternate keystroke input devices. These codestrings are invisible to other applications running on the system and to the user as well. The particular application of this concept to computer-based environmental control is highlighted.

Statement of the Problem

A common difficulty with computer-based assistive devices is trying to get them to work together. In a hypothetical computer-access/environmental-control scenario, an individual with high-level quadriplegia has purchased a voice recognition system for computer access and a computer-integrated environmental control system (ECS) for controlling appliances. The ECS is actually a peripheral device which receives its commands from special-purpose software running on the computer.

The voice recognition system is able to learn user-specific words and phrases. It is reasonable to expect that the user should be able to define macros so that common environmental control actions (e.g., turning on a reading lamp) can be accomplished with a single spoken command. Because the voice recognition system and the ECS were designed independently from each other, however, there is no direct way to control the ECS except through its software interface. To send a command to an appliance while working in a word processor, the user must switch over to the ECS control program, issue the command, and switch back to the word processor to continue working.

This need to move back and forth between applications is just an inconvenience; in no way does it prevent the user from controlling appliances. However, when the person is in bed and the computer is across the room, the system becomes much less practical for obvious reasons. Even though there is a reliable wireless link to carry the user's voice signal to the computer, there is no way to verify that the ECS control program is the one that will receive the keystrokes from the voice commands. If the user forgets to make the ECS program active before going to bed, his commands could just as easily be going into his word processor, and without looking at the screen it is impossible to know.

There are many simple back-up systems which could make this situation workable. The fact remains though, that the user has purchased a high-end system for communicating and controlling his surroundings, and as configured, it easily becomes unusable. The problem is not design flaws in the voice recognition system and the ECS, rather there is no reliable way to communicate the user's commands from one system to the other.

Background and Rationale

The idea for the software utility described here came from reports of successful combination of pointing devices with voice recognition systems [1,2]. In [1], Burnett et al. combined a headpointing device with a voice recognition system in a drafting application. To accomplish direct manipulation actions (clicking, double-clicking, dragging, etc.), the user would move the cursor to an object on the screen and say the name of the desired button pattern. The head-pointer provided the cursor positioning and the voice recognition system emulated the mouse buttons. One question arising from this report is, "What if the voice recognition system's designers hadn't thought to include mouse button emulation? Could these two devices still be combined in a useful way?"

Most, if not all, voice recognition systems allow the user to define new text strings and associated spoken commands. Assuming that the low-level mouse emulation functions (e.g., double-click) are available from elsewhere, a second application could be designed to bridge the gap between the voice recognition system and the desired mouse functions. The first step would be to program the voice recognition system to inject a special codestring for each low-level mouse function. The codestring would begin with a rarely used special character such as "~", and would have all of the information necessary to call the corresponding mouse function.

This "bridge" application would run in the background, monitoring the operating system's keyboard input queue. Upon detecting a "~", this program would start diverting keystrokes to itself. The program would continue blocking keystrokes until either it receives a valid, complete codestring, or it determines that the keystrokes coming in are not part of a codestring. In the first case, the target application (e.g., the word processor) would never see the keystrokes associated with the codestring. The bridge application would simply call the requested low-level function. In the second case, all of the keystrokes that had been swallowed would be re-injected into the operating system so that they arrive in the target application as normal.

Because the bridge application is monitoring keystrokes at the operating system level, there is no need for it to be the active application when a codestring is injected. The user could be working in a word processor and issue a codestring-based command without leaving the word processor. The codestring is "invisible" to the word processor, and the command is carried out in the background. Returning to the environmental control scenario, the user would be able to control appliances through his voice recognition system regardless of which application is currently the active one.

This scheme would not provide much additional benefit if all of the low-level functions needed to be designed into the bridge application once and for all; the bridge would just be providing static enhancements to the voice recognition system. (It should be just as easy to lobby the voice recognition designers for new features as the bridge application designers.) One of the major strengths of some popular operating systems is their built-in ability to link in low-level functions dynamically from a library on the disk. These "dynamic link libraries" (DLLs) permit applications to call functions that did not even exist when the application was written. As long as the application can find out the location of the DLL on disk and the name of a function within the DLL, that function can be loaded from disk and executed at run-time. This facility enables the bridge application to control any present or future hardware or software which has an appropriate DLL.

The fact that this bridge application could detect any codestring in the keyboard channel, regardless of its source, means that any alternate keystroke input device with macro capabilities could take on new control functions dynamically. A user could, for example, use an abbreviation-expansion program to define abbreviations that expand into valid codestrings. Suppose that the abbreviation "lo" expands into a codestring whose underlying DLL function turns on the desklamp. The user could be typing in the word processor, type the abbreviation, enter a space, and have the codestring injected. The codestring would never appear in the word processor because the bridge application would intercept it and call the DLL function to turn on the light. From the user's perspective, typing "lo" in the word processor turns on the light, and they never need to leave the word processor to do it.

This application is similar to a system proposed by Marsden and McGillis [3] which interprets patterns of switch activation into arbitrary low-level function calls within the operating system. They give an example of how the "escape" function might be triggered by closing a particular switch three times in two seconds. The system described here draws on this concept of mapping arbitrary input triggers into underlying operating system calls.

We chose to implement the system through the keyboard channel because of the widespread acceptance of transparent keyboard emulation: replacing the keyboard with more accessible devices that inject keystrokes in such a way that the computer cannot tell that they did not come from the keyboard [4,5]. There is such a variety of these transparent keyboard emulators on the market that the user would be able to accomplish the same low-level function calls through any number of input devices. The ability to offer more than one way to accomplish the same action in the interface presents at least theoretical opportunities to increase the ease and efficiency of access [6]. The keyboard channel is a natural backbone for such a multimodal input system.

Design

The codestring concept was tested with a prototype running under Microsoft Windows 3.1. An environmental control system was attached to the computer so that it could control a range of common appliances such as the telephone, television, VCR, and a variety of simple on/off devices like lamps. This ECS accepts commands through its serial port and it understands a protocol proposed by Hensch and Adams [7], similar to the one used for controlling modems. As an example, the command for turning on the television is

AT@IRR=POWER<CR>

Instead of building a general DLL function call utility, we focused on the DLL responsible for sending commands to the ECS. This simplified prototype still had the same basic function described above: detect a valid codestring and call the corresponding DLL function. However, the only DLL function it could call was the one for communicating through the serial port.

The codestring format consisted of three parts. The first part, a prefix, contained an unusual combination of three special characters (~!@). The next part was the string to send out the serial port, and a two character suffix (*%) terminated the codestring. The prefix served as a marker to begin the process of diverting keystrokes away from the target application and similarly, the suffix served to end this process.

The codestring detector was set up so that whenever a tilde (~) is received, subsequent keystrokes are immediately blocked from going to their usual destination. This presented an obvious danger that the system could become unresponsive to keyboard input, even when the user is not giving a codestring command. To reduce this risk, we decided that codestrings should only be sent as macro strings which meant that keystrokes would have to be coming in at a high rate for the system to continue blocking them. Any pause in keyboard input greater than 0.5 seconds would send the system back to its normal state (after the blocked keystrokes had been re-sent). If the user entered a tilde by itself, they might notice a slight delay before it appeared in the target application, but the system would not confuse it with the beginning of a codestring. Also, any unexpected characters in the prefix would immediately end the blocking process and any keystrokes that had been trapped would be re-sent.

Evaluation

The prototype was installed in an apartment at our hospital which is used for occupational therapy assessments. The apartment is equipped with a variety of devices that can be controlled with an ECS, including X10 modules and infra-red receivers. The codestring detector application was configured as described above, and it was successfully tested with a number of alternate input devices and software packages. For example, we were able to use the WiViK on-screen keyboard without any changes to the software to gain environmental control functionality. Abbreviations were simply added which would turn on and off a lamp, a fan, and the television. Similar results were obtained with a commercial voice recognition system.

Discussion

This codestring interpreter prototype demonstrates a new way of using existing keyboard emulation devices to achieve greater control over functions in the computer's operating system. It was possible to design this application because the Windows operating system supports the monitoring and swallowing of keystrokes. As well, Windows' heavy use of dynamic link libraries means that a codestring facility can be applied to devices and system services that were not yet designed when the codestring application was written.

The prototype designed here is only useful for sending strings through a serial port. A more general utility would be able to make arbitrary DLL calls so that any number of low-level system functions could be controlled. Environmental control is only one application. Other possibilities include mouse button emulation and mouse macros (e.g., press the closest on-screen button), application-specific control (e.g., copying files), and telecommunications (e.g., sending an e-mail message). Anything with a DLL interface could become an extension of the user's access system.

This idea is certainly not without limitations though. The primary usability problem is configuration. Before any new DLL function can be accessed, the user must configure the access system with an unintuitive codestring representing the desired DLL function call. Furthermore, the inner section of the codestring would need to come from the DLL's documentation. We would propose a scheme to embed the required configuration information directly into the DLL. The codestring utility would access this embedded information and present the user with a graphical icon-based representation of what the chosen DLL can do. The user might indicate the desired action by arranging the relevant icons together. For example, the DLL for controlling the ECS might contain a TV icon and a power switch icon, among others. Putting these two together on the screen would result in automatic generation of the codestring required to turn the TV on.

Acknowledgments

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Language Arts Keyboard Overlays for Students with Disabilities

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Abstract

The goal of this study was to demonstrate the effects of custom overlays for the IntelliKeys alternative keyboard on the participation and performance of students with disabilities in computer-based language arts curriculum activities. To determine this we compared the use of standard keyboards with the use of IntelliKeys custom overlays in activities that were otherwise very similar. We measured student productivity, attitudes toward self and peers, and the effects on the overall classroom community. The children participated in cooperative learning groups during all activities.

Background

The ability to communicate effectively in written format is one of the most critical prerequisites for school success. It is also one of the most demanding tasks that students, either those with disabilities or without such challenges, are asked to undertake. Early in their school careers students are expected to demonstrate mastery of spelling, handwriting, punctuation, and grammar while at the same time they are learning the process of formulating ideas and putting them down on paper. The demands for written production increase at each academic level. By the time students reach post-secondary education, writing abilities are one of the most predictive measures of potential academic success. Beyond the academic realm, the ability to communicate clearly in written format is fundamental to successful endeavors as an adult. While learning to be effective writers is a challenge for all students, those with either physical or learning disabilities face even greater obstacles. For many of these students the very opportunity to even be included in the regular classroom activities designed to create writing competence may depend on the availability of adapted curriculum and assistive devices. (Koppenhaver, 1991)

Research Question

Is a child with disabilities more productive and more successful with computer based Language Arts activities when using the IntelliKeys with custom overlays as compared to the regular keyboard?

Method

At the research site, a Chapter I school in Southern California, the classroom teachers brainstormed their curricular needs with the curriculum adaptations specialists from the project. Eight activities were created in response to these needs (four for the standard keyboard, four for custom overlays). The activities were based on the literature stimulus of two poems, one classic children's novel and one short storybook. In each activity the leader read a story or poem out loud to the class, and students were given a writing assignment based on the literature stimulus. Each literature stimulus was matched with a pair of activities. One activity involved the standard keyboard, and the second activity used a custom overlay to provide a means for comparison. The activities were led by the curriculum adaptations specialists who had been working in this school community on a regular basis prior to the study.

The 12 student participants worked in cooperative groups. Groups were composed of two children with disabilities — one with a physical disability and one identified as learning disabled— and one non-targeted student. Student roles were: editor, who also served as team captain; keyboarder, who worked on the overlay or the standard keyboard; and author, who directed the keyboarder in what to write. During each activity each student had a turn at every role. This group structure also allowed for observation of attitudes of peers without disabilities and the students with disabilities during all activities.

Observers collected both quantitative and qualitative data on the targeted students during the activities. Attitudinal information was gathered from both students and teachers by way of questionnaires. In addition, the student work generated during the activity was saved in individual files, printed for the students' portfolios, and used to measure productivity and work quality.

Results

Observer Ratings:

Observers rated the students on *Student Success*, and *Ideas Contributed*. *Student Success* was a measure of the ability to complete the expected task

Table I.

Comparison of averages of success rates. Scale was 1–5, 1 being "mostly unsuccessful," 5 being "mostly successful."

Student	Average success - standard keyboard	Average success - custom overlays	Difference between keyboard and overlay
Andrew	2	4	*+2.0*
Tomiichi	2.75	4.25	*+1.5*
Marcel	4.75	4.75	*0*
Zachary	3.25	4.65	*+1.4*
Adrienne	4	4	*0*
David	2.33	3	*+0.65*
Jonah	2.5	3	*+0.5*
Jesús	2.25	4.25	*+2.0*
TOTAL AVG.	**3**	**4**	***+ 1.0***

in the cooperative group. Observers recorded student performance for each targeted student during activities using a scale ranging from 1 to 5 where 1 was "mostly unsuccessful" and 5 was "mostly successful."

Table I provides the data on the average success rate for using the keyboard and overlay as recorded by the observer. All students were equally successful or more successful using the custom overlays as compared to the regular keyboard.

Ideas Contributed (see Table II) was a measure of how many ideas each targeted student contributed relative to his/her peers. The scale ranged from 1 to 4 where 1 was "significantly fewer" and 4 was "significantly more."

Student Opinion Forms:

Out of the eight activities completed, the students generally responded that they enjoyed seven. Only one activity was disliked by more than one student. This was a keyboard activity. Notably, the custom overlay activity it was paired with, which was the same format with a different literature stimulus, was the favorite activity of the class. In general, most students thought that everyone in the group was included and that everyone was able to say what they wanted to say for almost all writing activities. Students said that they liked to use the IntelliKeys because they didn't have to type out whole words, and because it was faster, easier, and more fun.

Teacher Surveys: The students' teachers filled out a survey after their students completed all eight of the activities. Teachers were extremely enthusiastic about the use of custom overlays in computer-based language arts activities.

Table II.

Comparison of averages of *Ideas Contributed* rates. Scale was 1–4, 1 being "significantly fewer," 4 being "significantly more."

Student	Average *ideas* rating -standard keyboard	Average *ideas* rating - custom overlays	Difference between keyboard and overlay
Andrew	2	3.5	*+1.5*
Tomiichi	1.66	2.83	*+1.17*
Marcel	2.75	2.5	*–0.25*
Zachary	3	3.33	*+0.33*
Adrienne	2.66	2.66	*0*
David	1.33	2	*+0.67*
Jonah	3	1.66	*–1.34*
Jesús	1.66	3.0	*+1.34*
TOTAL AVG.	**2.25**	**2.7**	***+0.45***

Student Work:

Of the four activity pairs, three were fill-in or matching activities that were evaluated based on the percentage of the activity that was completed correctly. One pair of activities was more open ended and was evaluated for student productivity and quality using a scoring system: writing samples were given a score of 1–3, with 3 being the highest. All student work evaluation was done with no knowledge of the subject or whether a standard keyboard or custom overlay had been used. In all circumstances, all students performed about the same or better with the overlay. For five students, their percent correct increased by about 40% to 60% when using the custom overlay. (Khalsa, A. Final Report 1995)

Discussion

The use of custom overlays with IntelliKeys implemented during this study provided a unique opportunity for students with disabilities to participate more fully with their peers in the area of written language. The custom overlays with the IntelliKeys Keyboard allowed students to press only one button on the keyboard and have an entire word or phrase "typed" into the computer. This same technology allowed students to press one "Delete" key and delete the entire word or phrase just typed. These custom overlay features with direct access to words and phrases provided the opportunity for a student to have a more personally satisfying and productive writing experience. By incorporating the use of IntelliTalk, a simple talking word processor, the students could press one "Read" key on the IntelliKeys Keyboard and have their written work read out loud to them by the computer. Hearing their own words proved to be a highly motivating experience for many students.

We learned that it was possible to create successful overlays for language arts activities and that the use of custom overlays enhanced the cooperative learning process. We developed strategies for measuring student success, student affect, and teacher affect. The data demonstrated that students gained productivity and success by using custom overlays and that the teachers found the use of the products to be successful for their students and classroom communities.

- *Student Success:*

We determined that students with disabilities benefited from IntelliKeys with custom overlays when compared to a regular computer keyboard. The data demonstrated that overall, students had higher levels of success, contributed more ideas, and were more productive and more accurate when using overlays. Observers noted that students worked more intently and were more on task while using the IntelliKeys Keyboard. Teachers reported that the students felt successful and took pride in sharing their work with the peers who were not participants in the study. An unexpected outcome from this study was that students spontaneously became "teachers" of both the lessons and the technology to other students. They exhibited a desire to share their skills with others.

- *The Cooperative Learning Process:*

The cooperative learning strategies employed during the Phase I feasibility study were enhanced by the custom overlays. Using the custom overlays, children of various abilities were able to take part in computer-based language arts activities. Children who were typically disruptive in class or in a group demonstrated a greater ability to stay focused and on task when using the IntelliKeys Keyboard and custom overlays.

- *Teacher Response:*

Teachers found that the use of overlays for language arts activities was a significant aid in teaching students with disabilities. It is significant to note that all of the teachers thought that the overlays enhance language arts skills, and that these types of activities are useful in the classroom.

In conclusion students were more successful and contributed more ideas using the IntelliKeys custom overlays than using the standard keyboards. Teachers reported positive changes in student attitudes toward writing, increased enthusiasm, and better student collaboration.

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THE EFFECTS OF TRADITIONAL AND NON-TRADITIONAL EDUCATIONAL METHODS ON PROMOTING INDEPENDENT SKIN CARE AMONG PARAPLEGIC ADULTS

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Abstract.

The present study explored the viability of employing Computer Aided Instruction (CAI) as an educational tool for promoting independent skin care among paraplegic adults residing in a free-standing rehabilitation hospital. Results indicate that CAI was more effective than traditional educational methods in increasing the initiation and performance of pressure relieving techniques every 20 minutes while seated, as well as the likelihood of the participants reporting that they completed a daily skin inspection. In addition, all three participants demonstrated gains on informal testing of skin care concepts. Implications of this study include the usefulness of CAI as an effective tool for educating paraplegic adults about skin care resulting in the achievement of the educational goals and behavioral outcomes established by the treatment team.

Background

Health care professionals continue to be challenged to identify effective intervention strategies that provide comprehensive health education in the area of skin care management for individuals who have experienced traumatic and non-traumatic spinal cord injuries (SCI). The need for exploring and creating new educational strategies becomes evident when considering the prevalence of skin breakdown among the SCI population in spite of traditional educational methods, the tremendous financial and personal costs associated with the treatment of pressure ulcers, and availability of instructional technology enabling health care educators to create stimulating interactive learning prescriptions employing CAI.

Traditional educational methods (i.e., classes incorporating audiovisual material, sporadic one-on-one instruction, and the provision of textual material) designed to teach patients strategies to prevent skin breakdown have fallen short of engaging active participation from the learner (e.g., patient). Sessions are often missed due to high levels of fatigue, scheduled diagnostic tests, and/or lack of desire/motivation on the patient's part to attend these "classes". One-on-one instruction, though invaluable and certainly necessary, is often lacking in consistency due to time and staffing limitations, not to mention discrepancies between staff in terms of individual teaching styles and level of knowledge and comfort(1).

Despite advances in technology designed to improve pressure sore prevention, pressure ulcers continue to be a critical and pervasive problem facing health care practitioners working with SCI individuals (2). Approximately 30% of all persons with SCI will develop at least one pressure ulcer within the first few years after injury. Pressure ulcers have been described as one of the most common factors causing delay in the timely rehabilitation of the SCI patient often leading to pain, a longer hospital stay, and a delayed recovery (3). Moreover, systematic tracking of pressure sore occurrence among the SCI population has prompted researchers to analyze the costs associated with treatment. Cost estimates to heal one pressure ulcer for the general population range from $14,000 to $40,000 (4). Hospital costs for pressure ulcer treatment in new SCI patients in the United States has been estimated to exceed $66 million dollars (5). Patient education has been identified as a potential factor in preventing the occurrence of secondary complications (i.e., skin breakdown) in the spinal cord injured patient (6). Computer based multi-media technologies and CAI present an exciting new dimension to education (7). Providing CAI could be an effective method to engage patients in the learning process to ensure acquisition of concepts leading to the achievement of the educational goals established by the treatment team. Employing CAI would enable paraplegic patients to access the educational workstation independently, afford privacy in the learning environment, and make instruction available when the patient is ready to learn (8).

Methodology

The participants who were involved in this study were two adult males and one adult female. The male patients (participants) had sustained non-traumatic spinal cord injuries resulting in diagnosis' of incomplete paraplegia secondary to a lesion or lesions at or below the first thoracic vertebral level. The female participant had sustained a traumatic spinal cord injury which resulted in complete paraplegia. A research protocol was submitted to an institutional review board (e.g., Behavioral Investigation Committee) and all participants were given an information sheet which outlined the procedures and explained the potential benefits and risks associated with this study. The observational settings utilized for this study were encompassed within Rehabilitation Institute of Michigan (RIM).

Learning was defined in terms of both cognitive and behavioral outcomes. Cognitive processing (i.e., acquisition of concepts) was measured via pre and post-testing and each participant completed a survey with Likert style questions which identified attitudes the participants held toward self-care. Both measures were completed prior to baseline data collection and as a post measure following the implementation of each treatment condition including traditional education methods (e.g., lecture incorporating audio-visual aids, sporadic one-on-one instruction, and the provision of textual material) and non-traditional methods (e.g., CAI incorporating two interactive multi-media modules). The pre/post-tests and surveys were read to each participant and their responses were recorded by the author or a research assistant. Targeted behaviors included: 1. Independent initiation of pressure relieving technique(s) (i.e., push-up raise, side-to-side raise, and forward lean) every 20 minutes while seated. 2. Independent performance of pressure relieving technique(s) while seated. 3. Independent performance of skin inspection on a daily basis. Methods of observation to measure behavioral outcomes included time sampled recording employing multiple probes throughout all phases of this study. The author and/or a research assistant examined the frequency and duration of targeted behaviors 1 and 2 via direct observation. Data collection for targeted behavior 3 was accomplished by the participants reporting to the author on a daily basis whether skin inspection was performed at any time during the previous day. These techniques were utilized because targeted behaviors could have been occurring throughout a 24 hour period every day, thus making continuous observation unrealistic.

A multiple baseline across subjects approach including an ABC (for 2 subjects) and AC (for 1 subject) single case experimental design was employed. This design was chosen: so that changes in the occurrence of participants demonstrating targeted behaviors could be compared to a baseline, as well as between treatment conditions, to strengthen the internal validity of treatment C by controlling for potential carry-over, and to demonstrate multiple replication of treatment effects on targeted behaviors. Analysis to determine if replication across three participants occurred was completed to support the hypothesis that CAI is a viable and efficacious method to educate paraplegic adults. Baseline (A) included: pre-and post-testing, observational recording of occurrences of target behaviors, completion of a Likert style survey reflecting attitudes toward self-care (i.e., skin management) and self-reporting. Initial or traditional treatment intervention (B) reflects the effect of traditional educational methods (i.e., lecture, sporadic one-on one instruction, audio-visual and printed materials) on targeted behaviors. The second or non-traditional intervention (C) reflects the introduction of an interactive multi-media computer workstation developed by Pellerito, Souri, and Homich at RIM. and its impact on targeted behaviors. The author acted as the primary observer and a research assistant assumed the role of the reliability observer. Reliability was achieved during a one week clinical trial resulting in 85%-90% agreement between observers.

Results

Results are presented in Figures 1, 2, 3, 4, and 5. Data for each participant are presented in vertically oriented graphs and analyzed in accordance with multiple baseline design.

Figure 1: Data from Participant 1

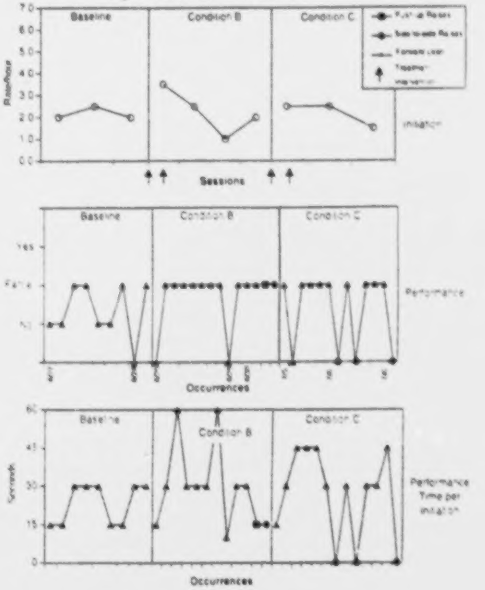
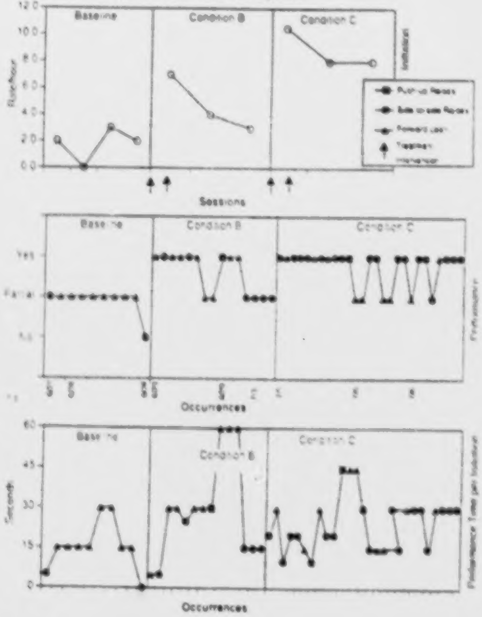


Figure 2: Data from Participant 2



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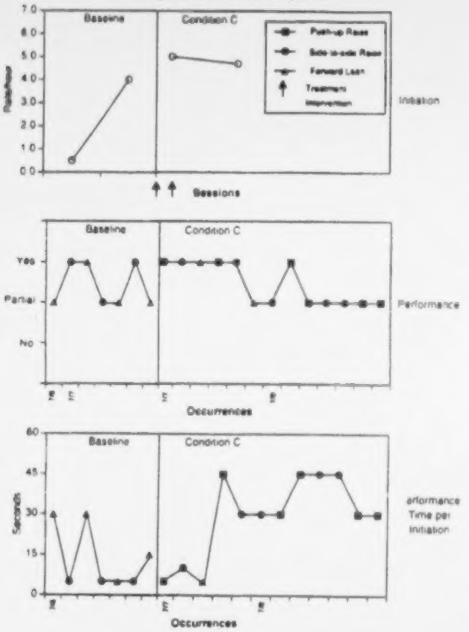
Figure 3: Data for Participant 3

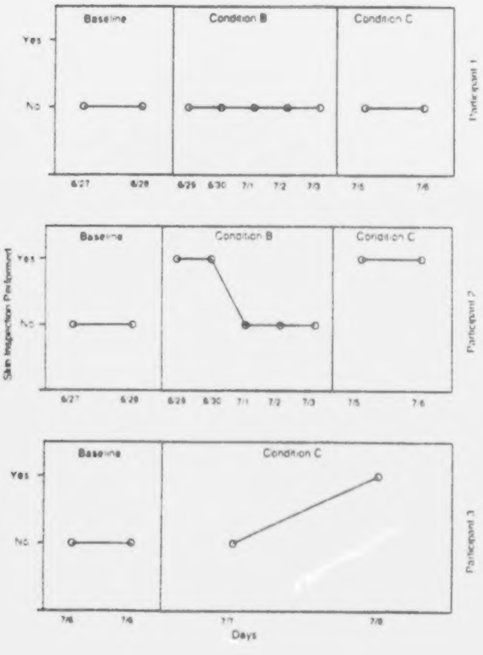
Figure 4: Skin Inspection

Discussion

The most important implication of this study is the importance of CAI in assisting paraplegic adults acquire and demonstrate skills necessary for optimal skin care management. Results indicate that CAI was more effective than traditional education methods in increasing the initiation and performance of pressure relieving techniques every 20 minutes while seated, as well as improving the likelihood that patients will perform daily skin inspections. In addition, all three participants demonstrated gains in the acquisition of knowledge relating to skin care concepts.

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A PILOT STUDY FOR MULTIMODAL INPUT IN COMPUTER ACCESS

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Abstract

Multimodal input in user interfaces has been suggested as a means to obtain more efficient and robust interaction. One promising combination for individuals with good head and voice control is speech recognition and head-pointing. While each modality combined with the proper technology can be used to control keyboard and mouse input, integration has a potentially synergistic effect.

This paper describes the overall research approach to studying integration of speech and head-pointing and the results of a pilot study used to refine the experimental tools and protocol. The research is based on the premise that speech recognition will have a natural advantage for typing text and that headpointing will have a natural advantage for mouse actions such as dragging. The first planned study will test this premise through a comparison of each modality for each class of task. However, given the significant differences between the devices, it is essential to understand the differences in learning curves for device use. The pilot study examined changes in performance over a large number of trials and supports (but does not prove) that a study with approximately five trials will provide useful comparisons.

Background

Many people with motor impairments (e.g., spinal cord injury) face difficulties in efficiently accessing computers and other information systems. One approach to overcoming these "bandwidth" limitations is to combine more than one modality in a synergistic way [3]. For example, in recent years the Apple Macintosh AV series has been available with simple speech recognition for common commands and controls. This can in may cases save the user from switching between the keyboard and the mouse.

Multimodal input has been investigated by a number of researchers in the AT community. Trevianus et al. [5] investigated the integration of speech with traditional single switch scanning and showed an increase in selection rate despite a limited number of vocalizations available from the subjects. Cairns et al. [1] developed a computer access environment that integrated speech, gesture, eye-gaze and pointing. Kazi et al. [2] have investigated multimodal control (using speech and gesture) of assistive robots that is combined with an artificial vision system and reactive planner. In reviewing multimodal approaches a number of potential benefits become apparent:

- An increase in bandwidth can result in improved speed
- An increase in redundancy may result in improved accuracy
- Multiple methods for achieving tasks provides 1) greater choices for users; 2) greater flexibility to changes in situation (e.g., environmental noise); and 3) additional ways to cope with fatigue
- An increase in naturalness of interaction may result in greater satisfaction and ease of use.

Because the nature of multimodal user interfaces is combinatory, there is a rich set of opportunities for research. Each particular combination of devices will bring a unique set of issues.The research discussed in this paper addresses the specific combination of speech recognition and head-pointing.

This combination is appealing because while products based on these modalities are both capable of mouse and keyboard emulation, it seems intuitive that they are each better suited to one of the tasks. Both keyboard and speech recognition-based typing are discrete tasks while mouse use and headpointing are continuous tasks. In addition, speech recognition systems are approaching the ability to accurately recognize large vocabularies without spelling.

Approach

The overall goal of this research is to explore issues arising from the combination of speech and head-pointing modalities as embodied in two specific products.[1] As mentioned each device is capable of providing complete access to mouse and keyboard functions. It is hypothesized that each device is better suited to one task. In particular, for most users speech recognition will be a preferred keyboard replacement and a head-pointing device will be a preferred mouse emulating device. If this hypothesis is proven correct then one can infer that integration will be beneficial. However, it will be also useful to explore these technologies in an integrated form to explore other possible benefits beyond using each device for its preferred task. For example, while users may prefer to use head pointing to control cursor position, they might prefer speech recognition for button actions (e.g., double-click). The research is being conducted in three major phases: 1) Both devices used separately for typing; 2) both devices used separately for mouse-based tasks; 3) combined devices used for a variety of tasks. Each experiment will be performed with approximately 15 non-disabled subjects and 5 disabled subjects. A more detailed discussion of the overall research plan is discussed by Smith et al.[4] which also presents results of a pilot study that examined different device parameters (especially learning configurations) in order to help define the overall protocol. The pilot study discussed in this paper primarily addresses the issue of learning curves.

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[1] The speech recognition system used in this research is the DragonDictate from Dragon Systems. The head pointing system is the HeadMaster used with WIVIK on-screen keyboard software from Prentke Romich Corporation.

Pilot Study Objective

For this research, a comparison is being made between two devices that are fundamentally different in their theory of operation, implementation and use. Because of this, there is a potential that actual use of the systems could have dramatically different learning curves. Since it is often impractical to evaluate use over a long period of time among a large number of subjects, it is necessary to limit the number of trials for each subject. If the system learning curves are in fact different, then results can be misleading. This is illustrated by a hypothetical example shown in Figure 1. Treatment A has a much steeper learning curve than Treatment B. If a study were carried out for 5 trials, then Treatment A would be deemed better despite the fact that in the long term (i.e., after trial 9), treatment A was superior. One approach to this problem is to let all subjects reach asymptotic performance. This can either be impractical or difficult to define. In fact the first pilot study of this research [4] showed a great deal of variability in speech recognition performance that would make it difficult to establish asymptotic performance.

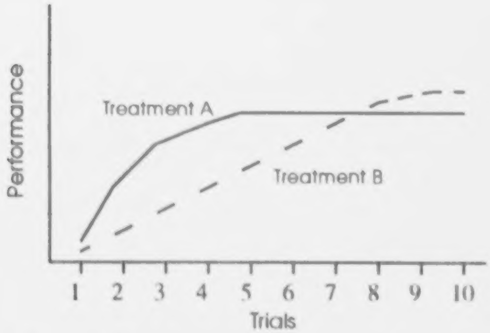

Figure 1: Hypothetical learning curves for very different interfaces may lead to misleading results if not well understood

Hence the purpose of this second pilot study was to explore long term use of both technologies with a single subject to better understand if there are any significant learning curve differences. The results would help define the number of trials used in the larger multi-subject experiment. This experiment was also used to finalize any other issues in the protocol or with the tools being used.

Method

This pilot study included one person who did not have prior experience with either input technology. The subject was a person without a disability and had familiarity with the computer. The subject was trained using the HeadMaster Plus technology with WiViK2 Visual Keyboard Version 2.1b, an on-screen keyboard with word prediction. For speech input, the user was trained using DragonDictate 1.0 for Windows, a discrete speech recognition system based on sound matching. Additional information as to the previous configurations of the input technologies being used can be found in Smith et al. [4]

In the pilot study, the subject typed a series of 160-word paragraphs further grouped into sets of three. The subject was given the option to pause in between paragraph sets. To ensure that the subject was ready to begin timing, a verbal cue for the DragonDictate System was given. For the HeadMaster Plus with WiViK the user had to select a specified key to begin timing.

During the training on both systems, the subject was given instructions on how to correct for errors. These instructions were derived and refined from the initial pilot study.

Results

The results of the pilot trials are shown in Figure 2. Although the DragonDictate performance is more erratic it appears to be consistently faster than WiViK. The average rate over seven trials for WiViK was 7.99 words per minute compared to 11.41 words per minute for DragonDictate. For all twelve DragonDictate trials, the average rate was 12.53 words per minute. More substantive for this pilot study, however, the results indicate that both input technologies are providing valid results after the first trial. Any learning component appears to be negligible after the first trial, especially for DragonDictate.

Discussion

After analyzing the results from Figure 2 we were able to determine the range of trials to be used in the formal experiment. We decided to use five trials such that each user will transcribe five data sets, in random order, using both input technologies. The first

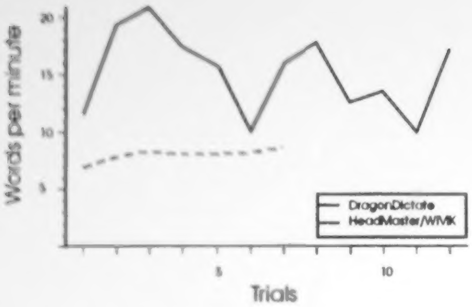

Figure 2: Pilot Study Results

trial will not be analyzed in order to compensate for learning.

Interaction and feedback from the user enabled us to make final modifications to the experiment design. These modifications were incorporated into this study and have propagated to the formal text generation experiment. The WiViK dictionary was augmented from the Brown Corpus. The new dictionary contains 5000 words arranged by frequency. The new dictionary has improved WiViK performance and has not created a bias toward paragraph content.

As a result of this study, the procedures for making corrections using DragonDictate were simplified. New procedures emphasize the use of the "scratch that" macro for deleting unwanted utterances and the "choose 10" command for removing the DragonDictate choice list as well as the current word. In addition, the procedures for providing instructions to the user were simplified. Instructions for DragonDictate have been typed onto a template and secured to the computer monitor.

A significant modification to the transcription process further emerged from this study. It was decided to transcribe the data sets line by line. Previously, the entire transcription paragraph appeared in the text editing window. The evaluation software was adapted to display a single line of text and advance the cursor two lines. The user transcribes the top line and invokes a 'page down' to erase the contents of the window and retrieve the next line.

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A COMPUTER-BASED ENVIRONMENTAL CONTROL SYSTEM

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ABSTRACT

A new environmental control system (ECS) has been developed which, based on clinical experience, satisfies a previously unfulfilled need of many clients. The University of Michigan ECS (UMECS) is a computer-based ECS which is flexible, inexpensive, and easy to use. This paper discusses the design of UMECS along with its advantages and underlying design criteria.

INTRODUCTION

Computer-based ECS's have several advantages over their stand-alone counterparts which they derive from the power of the computer they inhabit. A primary advantage computer-based ECS's enjoy is a dynamic display, which provides tremendous flexibility. Dynamic displays can change based on the operation that the user is carrying out, which simplifies both the user's interaction with the system and the design of the system's interface. Dynamic displays are also capable of changing to accommodate the specific needs of a user. Additionally, they allow graphic user interfaces, which make a program easier to understand and learn how to use. For example, a computer display can vary between word-based and picture-based representations or switch to extra-large print. While these changes are conceivably possible to implement on a stand-alone ECS with a dedicated display they are often ad-hoc in nature and difficult to optimize.

The computer's disk drive allows a computer-based ECS to provide the ability to store backups of environmental control system information permanently. This means that a sudden loss of power will not erase all of the data stored in the ECS, which can happen to a stand-alone system without a battery backup feature.

A computer-based system can make use of equipment that the client already has or will be purchasing to meet other needs. In such a situation, the addition of a few inexpensive environmental control devices represents a minimal cost for a complete ECS. In addition, for clients that spend much of their time in front of a computer, an ECS that is integrated with their computing system may represent the most accessible location for centralized control of their environment.

Another advantage of computer-based ECS's is that for many people it is easier to obtain funding for computer systems than environmental control equipment, because computers more clearly represent an opportunity for pursuing educational or vocational opportunities. ECS's, on the other hand, are often times difficult to justify to outside funding agencies, leaving individuals with the responsibility of purchasing environmental control equipment on their own.

Of course, a computer-based ECS is not a viable solution for everyone, particularly for those that do not own, or wish to use, a computer. If the ECS is integrated with the computer, a breakdown in the computer means losing both the computer and the ECS. A computer-based ECS, like many stand-alone ECS's, is not conducive to mobile operation. However, it is certainly possible that remote control similar to that available for some stand-alone ECS's could be developed for computer-based ECS's. For those individuals that desire the ability to control devices from several different rooms of their house, the most reliable solution currently remains to be the use of a smaller, mobile unit.

BACKGROUND

A variety of different computer-based ECS's have been developed over the years, and a complete review is not possible in the space allotted. However, a select few can serve as a representative sample of the field as a whole.

The Eyegaze System [1] provides environmental control and communication capabilities to individuals while only requiring consistent eye movement for input. While impressive in its capabilities, this system is extremely expensive and exceeds the budgets of most people.

The X10 Computer Interface [2] sits at the other end of the spectrum, in terms of both functionality and cost. The interface is inexpensive, but its accompanying software is limited, only providing access to the X10 Computer Interface, which constrains the control options which are available.

The Cintex computer-based ECS [3] is characteristic of many mid-priced computer-based ECS's. This system offers both infra-red (IR) and X10 control options and fairly sophisticated control capabilities. Unfortunately, while a great deal of design effort was devoted to the system's functionality, Cintex does not take full advantage of a computer's ability to reduce the complexity of a task.

Other systems, while presenting unique advantages, also suffer certain drawbacks. Some limit the user's ability to run other applications (spreadsheets, word-processors, etc.) while the ECS program is active. Others do not interact smoothly with the user's computer access method. Still others are too complex for an individual to install and support without extensive assistance.

STATEMENT OF THE PROBLEM

Based on our clinical experience, we felt there was a distinct lack of a system which was both flexible and powerful enough to meet the needs of many different clients while remaining sufficiently inexpensive that it could be purchased without significant outside funding. Our solution to this problem was to construct an ECS from a collection of inexpensive components and use a computer to provide a uniform method of accessing all of these disparate parts.

DESIGN CRITERIA

The most important criterion was that the ECS work with all of the different access methods that our clients use. These included mouse emulation, voice recognition, Morse code, and one and two switch scanning.

The system also needed to be simple to operate and support. For many clients, the computer we recommend is the first computer they ever receive. Neither they, nor their families, are prepared to provide extensive technical support for a computer system and they sometimes live too far away to receive frequent home visits for assistance. In addition, reducing the required amount of technical assistance also decreases the overall cost of the ECS by minimizing the amount spent on installation and support.

Another stringent requirement was that the ECS software not interfere with the user's ability to use the computer for other tasks. Ideally, the system would run in a multi-tasking environment, allowing the user to switch back and forth between other applications and the ECS easily.

In order to meet the needs of as many different clients as possible, the system needed to be highly flexible and configurable. The program could not limit the person to one television, or require that they sift through the controls for a stereo if they did not own one. The ideal system would allow the user to specify exactly what items were present in the environment that needed to be controlled and would only present the user with control options for those things.

Finally, the ECS had to be inexpensive. This included the software, the additional hardware that came with it, and all technical support. For most people, the reason they were pursuing this avenue of environmental control was a need to keep costs at a minimum.

APPROACH

The design of our new computer-based ECS, UMECS, was guided by feedback from rehabilitation engineers familiar with environmental control and is currently implemented for the Windows operating system. The program was written for the Windows operating system for several reasons. The majority of all IBM-compatible PCs come packaged with Windows and most new software being developed for the PC is aimed at running within the Windows environment. There exist several different computer access methods available for use with Windows including the recent addition of voice recognition, which is used by many people.

Windows also offers the distinct advantage of being a multi-tasking operating system. This allows a computer user to switch easily between UMECS and other programs without having to terminate one application to begin another. UMECS was written to require very little computer memory, in order to keep the maximum amount of computer resources available to run applications and the user's computer access method. Thus, at any time, UMECS can be placed in the background while the user runs other applications.

There are a myriad of controls available for Windows programs, including scroll bars, buttons, and "speed bars." Unfortunately, only a few of these are accessible to an individual who is not using a mouse or mouse emulator. The only control objects included in the user interface were those that could be operated with both the keyboard and the mouse. This allows any user with a functioning computer access system to operate UMECS without the need to construct elaborate access schemes to use any of the program's functions.

UMECS was written in C++ and compiled using the Borland C++ 4.0 compiler. Many of the advantages that UMECS enjoys are a direct result of an object oriented programming approach; the flexibility of the system is derived from the ability to treat every electrical device to be controlled as an independent object within the program. In addition, creating the user interface was also greatly simplified through the use of object oriented programming.

Three very flexible control components have been integrated into UMECS: the OneForAll programmable infra-red remote control [4], the X10 Computer Interface, and the Prenke Romich Scanning Director [5]. The OneForAll and the cable needed to attach it to the computer sell for less than $100 and can provide control over any infra-red remote-controlled device that the user owns. The Scanning Director is a trainable remote control that has the added advantage of offering switch access when not operated via computer. Through the X10 computer interface, a user can control power to any appliance that plugs into an electrical outlet (e.g.: radio, lamp, fan). The variety of X10 control modules which exist makes UMECS extremely flexible.

The user interface was kept as simple as possible, which reduces both learning time and the complexity of using the program. Each device that the user wishes to control has its own "virtual remote control." Adding a new device is as simple as adding another "remote control."

Because each device is considered separately from the intermediary hardware that is actually controlling it (i.e. - the OneForAll, Scanning Director or X10 Computer interface) the remote control that is presented to the user on the computer screen is tailored to the specific control options of its corresponding electrical device. Thus, for example, even though the OneForAll has a static keypad which must be general enough to incorporate the control options of all the different possible units that it can operate, the specific control options that the user chooses from when using the computer-based ECS are limited to those that are specifically applicable to the device being controlled.

DISCUSSION

The UMECS user interface offers several advantages when compared to an ECS with a static display. First of all, the display is greatly simplified. Only those options that are active are displayed at any time. Furthermore, it allows a flexible "plug and play" approach to environmental control. In order to add a new device to UMECS one simply plugs it in and then creates a virtual remote control within UMECS. To create the remote control the user specifies the type of device that is being controlled and the program automatically produces a remote control for it.

UMECS does not limit the user to a pre-determined set of electrical devices that can be controlled. The user can add as many devices as the hardware attached to the computer is capable of controlling. And, if the user does not need all of the control options these components offer, he or she does not have to scan through unused commands to reach the desired ones.

The flexibility of the program is enhanced by the possibility of multiple program configurations, each stored as a data file within the computer. At any time, the user can choose to load a file containing a set of appliances to be controlled or can start a new set. The user can use any number of different files, which allows the system to be quickly configured for different needs.

UMECS has been used succesfully by two of our clients. The first took full advantage of all its features and controlled lights, his television, and his stereo with the system. The second client uses UMECS to operate X10 devices in his home.

FUTURE DEVELOPMENT

UMECS as it exists now is a fully functional ECS. However, in order to increase its usefulness, several enhancements are planned, the bulk of which will be aimed at increasing the program's flexibility. Obvious improvements include adding to the number of environmental control components that UMECS can interface with. Other areas of the program that could be expanded include the variety of interfaces that the program is capable of presenting to the user; interfaces that are picture based or use very large lettering would increase the number of people able to use UMECS.

Finally, UMECS will not be complete until it fully addresses the issue of phone control. Currently, UMECS can be used to operate a switch controlled telephone, but in most cases this limits the user to answering and hanging up the phone and dialing the operator. One option is to take advantage of the built in phone-dialers that come with many computers, which is fine if the user's access method can operate the software supplied with the computer. Another method, which we are investigating, is to use a modem to operate a speaker phone. Many computers come equipped with modems at the time of purchase, so the added cost to a user would be limited to the price of a speaker phone.

UMECS has been very successful meeting the needs of two clients, and is applicable to the needs of even more individuals. This, coupled with the anticipated addition of the improvements discussed above, cause us to envision many more users for UMECS in the future.

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DR. GAIT III - A SYSTEM FOR GAIT ANALYSIS

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ABSTRACT

In this paper we describe a multimedia system for gait analysis supporting two distinct functions — tutoring and report generation. Dr. Gait III provides a means to view and electronically annotate all the information commonly present for gait analysis: medical history, physical examination, time/distance data, joint angle graphs, moments, powers, force plates, EMGs, video, and stick figures. It provides annotation functions for each type of data and also contains decision support tools to automatically annotate some types of data.

For tutoring, the annotation functions are combined with an audio recording system to record questions, hints, and answers. A suite of teaching cases is being developed for distribution with the program. The system may also be used as an authoring system for designing tutoring sessions for new cases.

For report generation, the same annotation functions are used. In addition the system provides a way to tag individual pieces of data for inclusion in a report. The report is then composed in a word processor where further editing can take place.

BACKGROUND

Gait analysis is the process of determining the cause of abnormalities in a patient's walking pattern so as to treat those abnormalities and improve the patient's functionality (1). A gait analysis session consists of several steps. First, the patient's physical characteristics such as leg length and weight are measured. Next, several range of motion parameters are measured such as the flexion/extension of the hip, knee, and ankle. Reflective markers are then affixed to the patient in various locations and a camera system records the trajectory of these markers in 3-D space while the patient walks. Surface or wire electrodes are also used to determine the muscle activity of the muscles of interest. This information is generally collected by computer and resides in electronic forms. In addition, most labs also record video of the patient walking.

PURPOSE OF THE SYSTEM

Many areas of rehabilitation engineering use data from a variety of sources and media types. In gait analysis, a study consists of numerical data, textual data, graphical data, and video. A study typically consists of a set of printed reports from several sources as well as video of the patient. This data is then used to generate the gait analysis report and is also often used for teaching students to perform gait analysis. Such tasks become easier when all the information is available in one place. A computer is ideal for this purpose as it can display and organize all the different kinds of quantitative information, the textual information, and the video. Looking at different pieces of information is as easy as selecting a different item from a menu.

For both report generation and tutoring purposes, one of the main functions needed is to draw a person's attention to pertinent pieces of information. We have developed a set of annotation tools for each type of information (text, graph, video) which add an appropriate type of visual change to an item in order to highlight that item. These annotations will be discussed further below.

Another benefit of moving the data to a computer-based form is that additional support functions can be added. For example Dr. Gait III can be instructed to automatically annotate regions of the graphs that are significantly different from normal. This function makes report generation quicker because it automates a step that the analyst would do anyway. Furthermore, for tutoring purposes it can serve as an example for how to do the gait analysis steps.

DESIGN

Dr. Gait III merges and expansion of two previous programs: GAIT (Gait Analysis Interpretation Tool) (2), and QUAWDS (QUalitative Analysis of Walking DisorderS) (3). GAIT is a tutoring system that pioneered the interface and tutoring functions that are now in Dr. Gait III. QUAWDS is a knowledge-based system for gait analysis of CP patients. It provides the basis for the decision-aid tools that are embedded in Dr. Gait III. QUAWDS' roots go even further back to the systems DR. GAIT-1 and DR. GAIT-2 (4).

Dr. Gait III uses data directly from the gait analysis laboratory. The data that can be viewed on-line includes: medical history, physical exam, time and distance data, joint angle graphs, moment graphs, power graphs, force plate graphs, EMGs, Quicktime video, and animated stick figures. The stick figures are generated from actual marker data by the program.

Data Annotation

Each screen of data may be annotated in a manner appropriate to the type of data. Text screens provide the capability to change the style (bold, italics, etc.) and color of the text. The colors that are made available have been chosen for saturation and depth such that they are distinctly identifiable when printed on a grayscale printer.

Screens with graphs provide two means of annotation — a colored highlight of a region and colored arrows that may be placed anywhere on the screen. Figure 1 shows an example of a red highlight and a green arrow on the sagittal joint angle graph for knee flexion. The user may place as many different highlights and arrows as they wish on a screen.

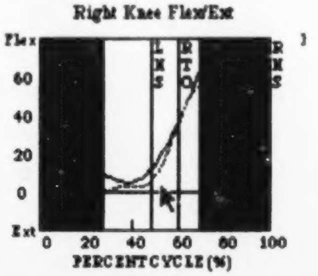


Figure 1: Right Knee Sagittal JAG

Video screens also provide two means of annotation for any frame of information — colored arrows and colored vectors that can be drawn on the video. In each case the annotations remain with a single frame of video and other annotations can be added to subsequent or previous frames without affecting other frames. Figure 2 shows an example of video annotation.

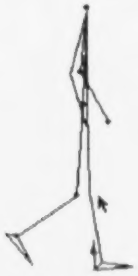


Figure 2: One frame of side stick video

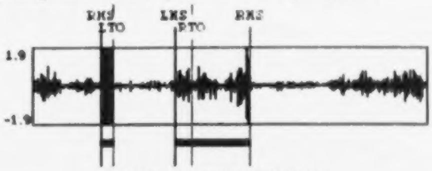
Decision Support

In addition to allowing the user to annotate items, we also want to provide decision support tools to aid report generation and tutoring. QUAWDS, provides a basis for these support tools. QUAWDS broke the entire task of gait analysis into several steps: finding determination, muscle fault generation, muscle fault rating, and generation of explanatory coverage of muscle faults (3). The first of these, finding determination, has been incorporated into Dr. Gait III for the joint angle graphs, physical exam and EMGs. For these data items, the system can automatically annotate the items that are abnormal.

In the case of the joint angle graphs, we have two methods available for determining abnormality — by standard deviation or by prediction region (5). Each of these methods highlights the abnormal regions of the graphs.

For the physical examination, Dr. Gait III uses a graduated system to determine whether the item is severely out of range or mildly out of range. Those that are severe are marked in red and those that are mild are marked in orange.

For the EMGs, the system uses a user-defined threshold to determine activity for 6 phases (weight acceptance, single limb stance - first half, single limb stance - second half, weight release, swing - first half, swing - second half). If the activity in a phase is all below the threshold and there is a normal indicating that there should be activity, then that region of the graph is highlighted to indicate disphasic activity. Similarly, if there is activity in a phase outside the threshold and the normal indicates that there should not be activity, then the region is also highlighted to show disphasic activity. Figure 3 shows an example of an EMG where the disphasic activity has been highlighted.



Right Anterior Tibialis

Figure 3: EMG showing disphasic activity

These various abnormality findings are then available for further processing by the decision support system. We are currently working to add the remaining subtasks from QUAWDS as decision support tools: muscle fault generation, muscle fault rating, and muscle fault explanatory coverage.

Tutoring

A teacher can annotate any of the several screens of data with the kinds of visual cues that were described above such as highlighted text and colored arrows. For each screen, the teacher also records up to 9 sets of audio comments, each consisting of a question, a hint and an answer. The student then reviews the case, listening to the questions (and hints if available) and records his own answer to each question. The student is blocked from listening to the teacher's answer until he has recorded his own audio answer. These student answers are available for later review by the teacher, but the student gets immediate feedback about the answer by listening to the pre-recorded answer.

We are currently developing a suite of teaching case for which the tutoring aspects have already been authored. In addition, the system may be used to author new cases for which no tutoring has been recorded.

Report Generation

Reports may be generated by annotating the data items with the program and indicating which items should be included in the report. Once the person is done marking items, the items are exported to a word processor where additional editing can take place and a hardcopy report can be printed. Currently the items that may be included in the report include: text screens (either an individual item or the entire screen), graphs, and single video frames. Markings made on the graphs and video frames are included in the report. In addition, we are working to incorporate report generation tools related to the decision aid tools. For example, a graph that has been highlighted by the system can be put into the report along with text describing the highlight such as "The flexion/extension of the right knee is decreased from 25 percent of swing to 50 percent of single limb stance." (This is the text that would be generated for the graph in Figure 1.)

EVALUATION

The system has reached the beta software stage. We are beginning evaluations of both the effectiveness of the tutoring system as well as the ease of use, ease of readability, and time-saving capabilities of the report generation system and the correctness of the decision support tools.

DISCUSSION

We believe that using a computer to display and annotate data can greatly enhance the performance of the people working with that data. For reports, this includes both the person generating the report and the person reading the report. By enabling the author of the report to arrange the information on a case-by-case basis, the report can be more concise and better organized. Putting all the data on the computer also allows the report author easier access to all the information necessary to write the report. Furthermore, providing decision support tools can increase the speed of report generation and also serve as a check on the person's knowledge by providing information that they may not have been aware of.

For tutoring, the system provides a way for the teacher to talk to the student without actually being there. The student's attention is drawn to the appropriate items visually while the student listens to the teacher's question. The student gets immediate feedback on his answer by listening to the recorded answer, and the teacher still has the opportunity to assess student progress by listening the students' recorded answers.

As the system is still under development, it is our intention to continue to expand and refine the tutoring, report generation, and decision support aspects of the system. We will continue to evaluate the various aspects of the system and make improvements where indicated.

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PC-BASED COMMUNICATION BOARD SIMULATOR FOR TEACHING

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ABSTRACT

The aim of this project is to provide a PC-based communication board simulator for teaching in a university course on assistive technology with a class size of twenty students. The simulator allows a student to explore different communication board configurations with or without digitized voice or sound output, and different phrase/sentence retrieval strategies. The hardware and software requirements of a PC required to develop the simulator and that to run the simulator are described. Using communication board simulators for teaching is cost effective in view of the number/variety required and the high cost of commercial products. This approach is also flexible because the behavior and functions of a PC-based simulator can be readily changed and expanded when the need arises.

BACKGROUND

Using simulators for training is not new. Well known examples are those used for training pilots and astronauts. In industrial applications, simulation is a cost effective way to offer training in a safe and controlled environment. In business and military applications, simulators in the form of games provide immediate feedback to actions taken under different scenarios.

The use of simulators for teaching is relatively new. With the availability of low cost personal computers, software simulators have gained popularity especially in the teaching of technical subjects where the actual construction of circuits and devices or the use of real objects are too time consuming and expensive. An outstanding example is the ubiquitous PSPICE, an electronic circuits simulator, used in all courses dealing with electronic circuits.

STATEMENT OF THE PROBLEM

In the teaching of assistive technology, assistive devices for the disabled is of particular interest to paramedics and engineers. Assistive devices are generally expensive because of the large variety required to satisfy different needs and the relatively small volume for a particular type of device. Electronic aids for communication are particularly fast changing, tailing closely the development of electronics and computing. Acquiring state-of-art devices in sufficient numbers for teaching is unrealistic. Considering cost alone, a portable device with speech output costs from a few hundred US dollars to several thousand dollars. At present, there is no simulator of communication aids for the disabled available.

RATIONALE

In general, an electronic communication board is a portable device which has a number of positions. Each position has an associated light and a tag on which a picture, phrase or symbol can be attached. The lights will advance in a prescribed scheme and the user communicates by selecting one or more positions. A position is selected when the user activates the ability switch when the light reaches the desired position.

As previously described, an electronic communication board is essentially an event-driven graphical interface for a disabled user. In other words, an internal event by a built-in timer controls scanning of the symbols, and an external event in the activation of an ability switch by the user selects a symbol. The Windows platform is well suited for graphical applications. Visual Basic, an event-driven programming language specifically designed to develop Windows applications, is most suitable for the development of PC-based communication board simulators.

For teaching purposes in a laboratory setting, portability is not an issue and a desktop PC with a sound card can be used to simulate an electronic communication board with speech output. The monitor screen can display the panel of a communication board and the sound card can provide excellent speech output. The hard-disk that comes with a desk-top PC has a large storage capacity which is well suited for storing audio files as well as `storage-hungry' image files.

In terms of cost, PCs are already available for general teaching. The cost of adding a sound card and speakers to a PC is very low compared with the cost of even a low priced commercial communication board.

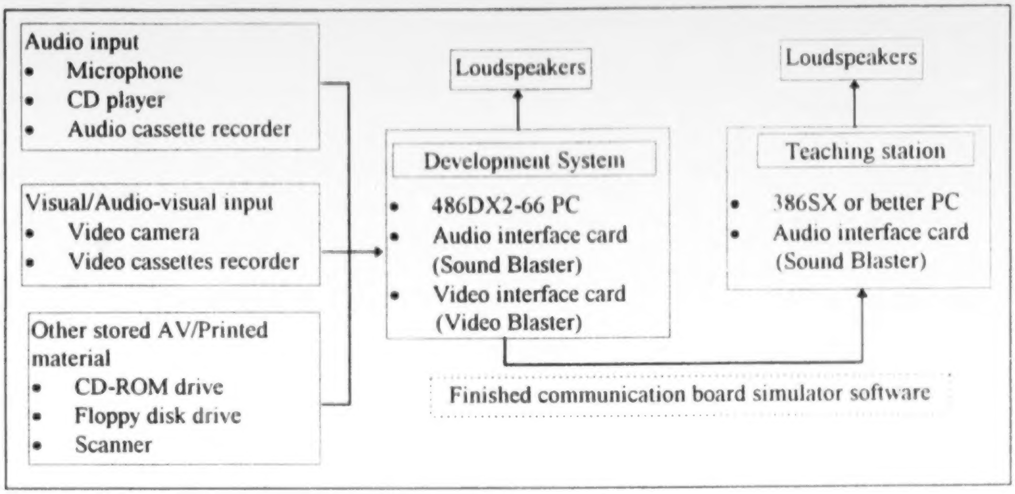

Audio input
Microphone
CD player
Audio cassette recorder
Visual/Audio-visual input
Video camera
Video cassettes recorder
Other stored AV/Printed material
CD-ROM drive
Floppy disk drive
Scanner
Loudspeakers
Development System
486DX2-66 PC
Audio interface card (Sound Blaster)
Video interface card (Video Blaster)
Loudspeakers
Teaching station
386SX or better PC
Audio interface card (Sound Blaster)
Finished communication board simulator software

Fig. 1 Communication board simulator development system and teaching station

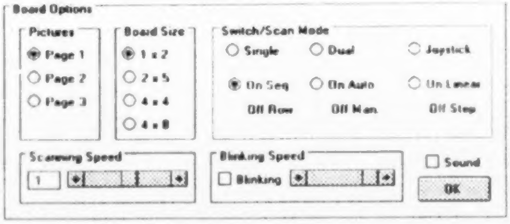
IMPLEMENTATION

Fig. 1 shows the Development System and a Teaching Station. The Development System consists of a 486DX2-66 PC with a CD-ROM drive, a sound card and a video card. A Teaching Station needs only a 386SX or better PC with only a sound card.

The sound card serves as the audio interface for audio input/output. Audio input can be recorded live using a microphone or from pre-recorded sources such as a CD player or cassette tape recorder. The sound card has built-in output audio amplifiers to drive a pair of small loudspeakers. The video card serves as the video input interface for sources such as a video camera. The rich sources of digitised AV material such as clip-arts and sound files can be inputted using the CD-ROM drive. Printed images can be captured using a desktop scanner.

The Development system requires Windows and Visual Basic for developing the simulator software. Visual Basic does allow compilation of an application into a true .EXE file that can be run under Windows with only a run-time DLL. In order words, there is no need to install and paid for a license of Visual Basic in a teaching station.

Fig. 2 shows the Communication Board Emulator 'options' screen. It allows the student to choose communication board matrix sizes from 2 x 1 to 4 x 8. Common scanning techniques using various ability switch configurations can be accommodated. Symbols can be stored in 3 different pages to increase the number of symbols in a given matrix size or to allow organization of the symbols for different situations, such as those in the home or school environment.


Board Options

Pictures
● Page 1
○ Page 2
○ Page 3

Board Size
● 1 x 2
○ 2 x 5
○ 4 x 4
○ 4 x 8

Switch/Scan Mode
○ Single ○ Dual ○ Joystick
● On Seq Off Row ○ On Auto Off Man. ○ On Linear Off Step

Scanning Speed
1

Blinking Speed
☐ Blinking

☐ Sound

Fig. 2 Communication Board Simulator: a portion of the 'Options' screen

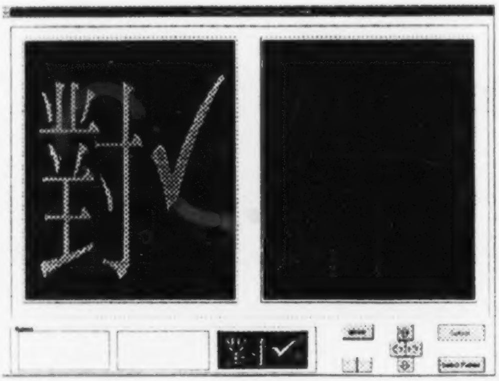


Fig. 3 Communication Board Simulator configured as a 1 x 2 board

340

BEST COPY AVAILABLE

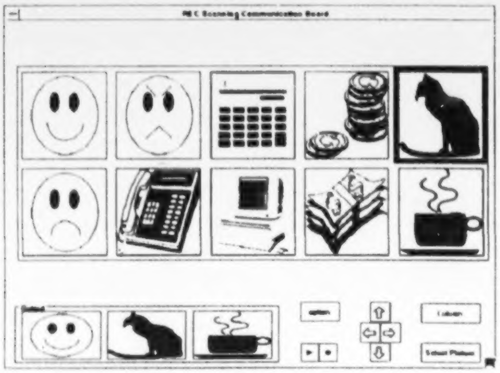


Fig. 4 Communication board simulator configured as a 2 x 5 board.

Fig. 3 shows a possible arrangement of a 1 x 2 board with the symbols for 'Yes' and 'No'. A voice message for each symbol can be recorded if desired. Fig. 3 shows one possible page of a 2 x 5 communication board. The student can choose up to three symbols and record a message corresponding to this particular symbol sequence if audio output is desired. Using a symbol combination to identify a given message enables selection of a large number of messages using a limited number of available symbols. For example, the three chosen pictures in Fig. 3 can be used to retrieve the message "I like cats and I like to drink hot tea.".

DISCUSSION AND DEVELOPMENT

The Communication Board Simulator as described is designed for teaching purposes. The student will have a chance to explore different message retrieval strategies and gain hands-on experience on their limitations and how that affect communication efficiency. In this regard, the limitation on the matrix size and the lack of other useful message retrieval strategies, such as 'picture-stringing' is not a major problem.

One shortcoming in this present implementation is that only the cursor keys are used to simulate real ability switches. One very simple way is to provide a 'break-out' box for the cursor keys of the standard keyboard which only requires minor technical work. A more elegant way is to use the games port for switch input. In this case software code has to be added to drive the games port and some hardware interface has to be provided between the ability switches and the games port. In either technique, the real limitation is the budget required to purchase the ability switches.

Since the simulator is software based, the user graphics interface in terms of matrix size and functions such as picture-stringing can be implemented without any change of hardware. Under the Windows environment, a retrieved message can be a full-motion video - a function that is uncommon even in expensive commercial products.

The simulator will be used this coming term in a course on assistive technology. The course has a class size of twenty students mainly of paramedics. The simulator will be used in laboratory sessions and possibly provided to students for home assignments. The simulator will be modified according to student feedback and developments in the commercial sector.

ACKNOWLEDGEMENT

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SIG-12
Rural Rehabilitation

INDEPENDENT RIDER

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ABSTRACT

Many people in this country enjoy horseback riding as a form of recreation and relaxation. The fact that a person has a disability presents challenges that most horse enthusiasts do not face. The consumer for whom the independent rider was developed uses a specialized saddle and rides regularly with his two sons who assist him in saddling and mounting his horse. The purpose of this project was to work to find a way to allow persons with paraplegia to saddle and mount a horse without the assistance of others.

BACKGROUND AND RATIONALE

There are many equestrian organizations for people with disabilities in the United States, but we were unable to find any that had or were aware of a lift system and containment system that could be attached to a horse trailer, thus allowing a person with paraplegia to use it both at home and on trips. Following several meetings with the consumer, the following design characteristics were identified:

- A lift system with remote controls that would allow the consumer to lift his saddle and then himself out of his wheelchair and onto the horse's back.
- A containment system capable of keeping the horse in place under all circumstances.
- Provisions allowing both the lift system and the containment system to be folded against the trailer for transport and unfolded for use by a person in a wheelchair.
- In designing all these features, using the simplest and most cost-effective method available.

DESIGN AND DEVELOPMENT

The Independent Rider consists of two major components, a horse containment system and a lift system. The containment system is built of 1" square tubing designed to hold the horse in a contained position for saddling and mounting. The system is hinged so it can be folded up against the side of the trailer when not in use or when it is being hauled from one place to another. The lift system involves a 12 volt battery-powered electric winch with a lift capacity of 1500 lb. In addition, a derrick was built out of 2" square tubing and designed to support the winch. The winch is attached to a frame built over the top of the trailer out of 2" square tubing. The lift or winch is controlled using a remote control switch attached to the winch. When not in use, the winch can be folded down against the side of the trailer so that it will be out of the way.

EVALUATION

The design for the Independent Rider was reviewed by several faculty members, and each dimension was carefully considered by the consumer. Particular attention was given to safety, portability, and utilization of components readily available.

The fabrication of the Independent Rider was a major part of the project. In the interest of safety, a professional welder reviewed the plans, our assessment of the project's feasibility, and then constructed the lift system. The design was simple enough and components readily available to facilitate easy duplication and/or modification for other interested individuals.

DISCUSSION

At this point, the lift has been constructed and field tested by the consumer and determined to meet his need. Also developed is an owner's manual and safety recommendations. These will facilitate further modifications or adaptations as needed. Detailed plans for replicating the independent rider have been developed and are available from the authors.

INCREASED INDEPENDENCE FOR FARMERS WITH A PHYSICAL DISABILITY

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ABSTRACT

When faced with the reality of a physical disability many farmers see accessing the tractor or combine as an obstacle to their returning to their farming operation, especially when the farmer is limited in his or her climbing ability due to a mobility impairment. The Pilot Lift, a vertical screw chair-lift, was first conceived when a farmer with a disability in Vermont approached the Agricultural Engineering Department at a midwest university to develop a chair-lift to access his tractor. A prototype was developed and tested, and Round Grove Machine Inc. was approached about the feasibility of commercially developing a quick, reliable, quality-built product that would allow a farmer to continue his or her farming operation after a disabling accident or illness.

INTRODUCTION

The National Safety Council has ranked agriculture as one of the most dangerous professions in the United States. Data from 1994 university studies indicate that approximately 140,000 disabling injuries occur each year to American farmers. Studies indicate that the total population of farmers/ranchers with spinal cord injuries in the United States is estimated to be between 4500 and 6500 with approximately 250-300 new spinal cord injuries occurring each year.
When faced with the reality of a physical disability many farmers see accessing the tractor or combine as an obstacle to their returning to their farming operation, especially when the farmer is limited in his or her climbing ability due to a mobility impairment. Many times farmers design and fabricate their own chair-lifts; most are functional but are not suited for universal commercial applications. The need for a chair-lift which is low maintenance, easy to access and operate, and most importantly dependable is foremost in the minds of farmers with physical disabilities.

DESIGN AND DEVELOPMENT

Initial studies of the problem indicated that there was a need for a chairlift attachment for tractors and combines that would provide the following:

1. A seat or platform that would lift the operator from the ground to a position that would enable him/her to transfer into the operator's seat.
2. Easy installation on the tractor or combine with the least amount of alterations to the original equipment and minimum interference with the operator's vision.
3. A design that was powered by the electrical system of the tractor and did not depend on the operating engine for operation.
4. A lift speed of approximately 5 feet/min and a lifting capacity of at least 300 pounds.
5. Fail-safe lift operation that would protect the operator in the event of power or drive mechanism failure.

During the 1980's, a variety of prototype lifts were developed and tested by C.B. Richey at a midwest university. Several concepts were examined, including a vertical winch-lift with a slide through seat, vertical lift platforms operated by winch and cable or by hydraulics, parallel linkage lift, a seat mounted on inclined rails raised by a winch and cable, and a vertical screw lift. The vertical screw lift has proven to be the most adaptive to the greatest number of applications. In 1987, Hubert Von Holten owner/operator of Round Grove Machine Inc. in West Lafayette, IN decided to commercially develop a reliable, quality-built chairlift that would allow a farmer to continue his or her farming operation after a disabling accident or illness. To date, approximately 150 of these units (Pilot Lift) have been installed on agricultural tractors and combines. Variations of the Pilot Lift have also been used in other agricultural and recreational applications.

The original proto-type of the Pilot Lift underwent several minor and major design changes as Von Holten gained experience in producing the lifts and working closely with agricultural clientele. The most significant of these design changes was the introduction of two more electric motors located at each end of the swing arm which allow the swing arm to pivot 360⁰ around the mounting unit (Figure 1). Other changes include the addition of a bellows around the screw to eliminate dust and dirt from affecting screw operation and the attachment of the seat from a suspended pole which allows the lift seat to be placed within easy transfer distance of the operator's seat on the tractor or combine.

The Pilot Lift is operated by a six button (3 pairs) umbilical control box. Each pair of buttons controls one of the three motors. Two of the motors are located on the swing arm and the other motor is located at the top of the screw jack. The motors are all 1/4 hp 12 volt reversible DC electric motors. The mast and screw are custom cut to any specified length depending on the application.

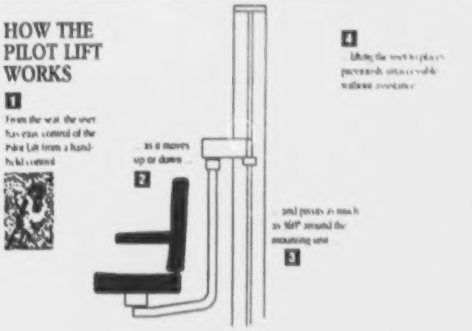
HOW THE PILOT LIFT WORKS
1
From the seat the user has easy control of the Pilot Lift from a hand-held control
... as it moves up or down ...
2
... and pivots as much as 360° around the mounting unit ...
3
4

Figure 1

The Pilot Lift will continue to change as the needs of farmers/ranchers with physical disabilities continue to change. Each unit is custom-designed to the individuals' tractor or combine to provide easy access and an increased independence for farmers with a disability.

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ACKNOWLEDGMENTS

Breaking New Ground Resource Center

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SIG-13
Assistive Robotics and Mechatronics

AN INTEGRATION IMPLEMENTATION USING AN M3S INFRASTRUCTURE WITH CONSIDERATIONS FOR USERS, PRESCRIBERS AND DEVELOPERS

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ABSTRACT

There are a wide range of technical aids available to persons with disabilities; these devices help them in their activities of daily living. This paper examines the applicability and appropriateness of the proposed rehabilitation communications standard, M3S, both in concept and implementation, in the context of three former clients with high level spinal cord injury who are users of technology. This paper also describes an M3S system implementation presently underway, and concludes by proposing one way in which M3S may be promoted, disseminated, and (ultimately) incorporated by rehabilitation developers, manufacturers and prescribers in North America.

BACKGROUND

Many assistive devices are available to persons with disabilities. These devices range from powered mobility, augmentative and alternative communications (AAC), environmental control, vocational tools (e.g. office equipment), to other more custom-devices (e.g. robotic manipulator). These technical aids have significant benefits for persons with disabilities in their daily living activities. We have approached three former clients of The Hugh MacMillan Rehabilitation Centre with regards to the types of practical assistive technologies they presently use in their home and work environments.

All three have sustained high level spinal cord injuries, and are frequent users of assistive technologies. Their typical system configuration consists of a powered wheelchair platform with interfaces to an onboard environmental control unit and a commercial home automation system; all three clients are also users of a computer oriented workspace. One of the clients has tested and used the Myoarm, a wheelchair-mounted robotic manipulator developed at The Hugh MacMillan Rehabilitation Centre [1].

STATEMENT OF PROBLEM

There are three main environments in which assistive technologies play a role. These are: (i) the wheelchair environment; (ii) the home environment; and (iii) the workspace environment.

Wheelchair environments consist of a commercial powered wheelchair platform and a corresponding input device (e.g. sip-and-puff, ultrasonic head switch); the wheelchair provides mobility and allows for physical access to other parts of the environment (workspace, home and community environment). Furthermore, due to restricted ability to access and control other types of devices in the other environments, the wheelchair input device typically incorporates some of the control modalities of the other two environments. Within the home environment, the functions typically accessed include: telephone and answering machine, entertainment systems (e.g. TV, VCR), lighting control, and door control; these functions are accomplished either through on-board (powered chair) or fixed location control (e.g. separate sip-and-puff). This functionality provides a measure of independence in daily living. It should also be noted that the bed environment is a subset of the home environment, and represents an important control location for the user outside of the wheelchair. The workspace environment includes the computer, monitor, printer, fax and related technologies, all accessed through each individual's control devices.

The persons with high-level spinal cord injury whom we have informally surveyed, and others with regressive conditions, often have difficulty operating devices, and yet they must be able to reliably control more devices than most people. Our clients' current systems are composed of combinations of different technologies performing different tasks or functions, each operated by their own input and control methods. Entertainment systems are typically controlled via IR switches and scanners, wheelchairs are controlled by direct switches (sip-and-puff), lights by X10 or remote X10, and telephones by other input methods.

Most of the access efforts to date have focused on the development and refinement of specific classes / brands of devices / appliances. The integration of control across the environments

Most of the access efforts to date have focused on the development and refinement of specific classes / brands of devices / appliances. The integration of control across the environments typically incorporates an ad hoc approach and custom hardware interfacing; this is due to the need to tailor access methods to the individual client on the one hand, and to the lack of an infrastructure around which to build the system on the other. As a consequence, if a user's ability level changes (e.g. from being able to control a four switch joystick to a sip-and-puff control) or a new function is needed, the system must be reconstructed. The encumbrance of modifying an existing control system often exceeds the available resources due to the diversity of systems, their proprietary nature, and need to revise the existing control structure. The latter case was described by two of the clients.

PROPOSED SOLUTION

A task-based system addresses the issue of integration of control. Such a system would be built around the tasks to be accomplished, which are tailored to the individual client's needs [3]. The main obstacle to its implementation is the large interfacing effort required, and the lack of a communications infrastructure for the modules [4]. An open rehabilitation communications standard would allow devices to be developed independently and maintain interoperability; furthermore, a standard would provide a well-defined means for interfacing device interactions to the home and workspace environments. This standard has been proposed in Europe by an international consortium, and is known as Multiple-Master Multiple-Slave (M3S) [5].

OVERVIEW OF THE M3S PREMISE

M3S is a proposed open communications standard for the rehabilitation environment. The M3S protocol defines the physical communications medium (CAN bus), as well as the message format of the information to be exchanged. There is presently no non-proprietary North American counterpart to the proposed M3S standard.

M3S operates as a task-based system in which tasks that need to be performed are defined from the various device modules attached to the bus; these tasks are defined in the system configuration software as opposed to being hard-wired. In order to achieve this, M3S makes use of the concept of degrees-of-freedom (DOF), which refers to the number of independent control parameters of a device. Degrees-of-freedom may have descriptive groupings (e.g. digital DOF for individual switches, analog DOF for joysticks); they may also be grouped by use, i.e. input degree-of-freedom (IDOF), or output degree-of-freedom (ODOF). A typical joystick has two degrees-of-freedom because it has two independent control parameters (Forward and Back as one, and Left and Right as the other). With this concept persons and devices may be described in terms of available and required DOFs respectively. The M3S system has a Configuration and Control Module (CCM) which is a program used to match the available inputs to the necessary outputs.

M3S SYSTEM IMPLEMENTATION

A project is presently underway at The Hugh MacMillan Rehabilitation Centre. The project goals are to develop a communications infrastructure for integration of control using a task-based control structure, and to develop a better means of interacting with the other environments (home and workspace). The tasks to be performed determine the number and type of modules that are to be incorporated into the system. There are two stages to the project: the first stage involves the implementation of M3S on a commercial (Invacare) powered chair platform. One of the M3S modules to be developed includes an RF remote link. The purpose of the link is to allow for transparent control of other systems without the constraint of being tethered to a fixed location. The second stage involves the development of a means to interact with a commercial home control system (CEBus). Development efforts are presently underway.

The M3S system requires the use of embedded control. This allows both flexibility of the overall system, and simplifies any subsequent modifications or expansions that need to be made. The tradeoff is that the system is technically more involved (i.e. use of embedded control). From the user and prescriber's perspective, this is additional involvement is not noticeable, and the main advantage is flexible configuration of the task tree, allowing the control structure to be more easily tailored and optimized to the user's needs. For the technologist/engineer implementing M3S modules, development of device application programs are greatly simplified as system knowledge is not necessary.

DISCUSSION

The M3S premise is both applicable and appropriate in the context of our work with our three former clients. The implementation presently under development represents a new approach in that a task-based system tailored to the individual user is built around a defined infrastructure; this defined infrastructure allows extensions and modifications to the user's system as necessary. Furthermore, the M3S system appears to provide a coherent means of accessing the other environments, such as home automation systems (e.g. CEBus). There are other potential applications for M3S, which may include roles as a tool for assessing different powered wheelchairs and control strategies. The flexibility in M3S is also applicable to control a sensory stimulation environment or a snoezelen room. Thus, further exploration of the M3S concept is appropriate.

In order to disseminate the idea of M3S, and to explore other potential applications, our group is pursuing the formation of a North American (NA) counterpart to the European M3S Consortium, but with a slightly different function. Aside from maintaining and refining the protocol, the main role of the NA-M3S Consortium would be to promote and disseminate expertise and information. A consortium offers a cost-effective approach, and allows for cost-sharing. It also allows for input and feedback from a broad spectrum of developers, manufacturers and prescribers.

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NOTE

Devices used include TOSC, CHEC I/II, Tykriphone, Peachtree controller, Unidialler, X10 controller and modules.

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HUMAN-COMPUTER INTERACTION WITHIN ROBOTIC WORKSTATIONS

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ABSTRACT

This paper describes recent research in human-computer interfaces for the command of rehabilitation robot systems. An iconic interface providing drag and drop interaction has been developed. This interface integrates with the Cambridge University Robot Language (CURL) to facilitate intuitive operation of structured robotic workstations by users of pointing input devices. The evaluation of this interface is presented in the context of experimental work with a number of alternative user interfaces.

BACKGROUND

CURL is an established interactive robot control environment which has recently been commercialised [1]. The CURL environment facilitates both direct control and task-level control of a robot arm and has been specifically designed for applications in rehabilitation. The software runs under Microsoft Windows and embodies the standard look and feel of Windows applications. It also incorporates a Dynamic Data Exchange (DDE) server which allows robot command to be initiated from other application software running on the Windows desktop.

A number of software-based access products are now available for Windows. These products enable non-keyboard users to gain full control of all applications on the Windows desktop using alternative input devices. It has not, therefore, been necessary to make provision for non-keyboard users within CURL itself.

Results from earlier research have indicated a requirement for user interfaces more closely tailored to the tasks of a specific robot installation [2]. Others have observed that shortcomings in the user interface can act as major deterrents to the widespread adoption of assistive robotic devices [3]. The work described in this paper has arisen from the search for a rapid development and evaluation strategy to facilitate the implementation of alternative customised user interfaces.

AN ICONIC INTERFACE

The benefits of graphical user interfaces which facilitate the direct manipulation of data are now widely acknowledged. Substantial research in the area of generic direct manipulation interfaces has demonstrated the following beneficial concepts [4]:

- Continuous representation of objects and actions of interest
- Use of labelled buttons rather than a complex syntax
- Incremental operations which are readily invoked and have an immediate effect

In designing a iconic user interface providing drag and drop interaction, the author has attempted to realise these benefits in the context of robot command. The prototype interface was developed using Microsoft Visual Basic 3.0 running under Microsoft Windows 3.1. This programming environment is well suited to user interface development in that visual components may be assembled rapidly and evaluated 'on screen' prior to the coding of underlying actions.

The interface allows each significant object within a robotic workstation to be represented by an icon within an interface window. The icons may be arranged to replicate the spatial relationships existing between the objects they represent. Each icon has an associated caption which is displayed as text immediately below the image. In addition, an image may be displayed behind the icons to clarify their meaning as necessary. The facility to drag an icon and drop it over another icon may be enabled on an individual icon basis. Robot tasks may be associated with specific combinations of drag and drop operations by entering CURL commands into a command matrix. Further tasks may be associated with the action of double clicking on the icons. Commands are sent to CURL using Dynamic Data Exchange.

INTERFACE EVALUATION

An evaluation of the prototype iconic interface was undertaken with the assistance of five potential users

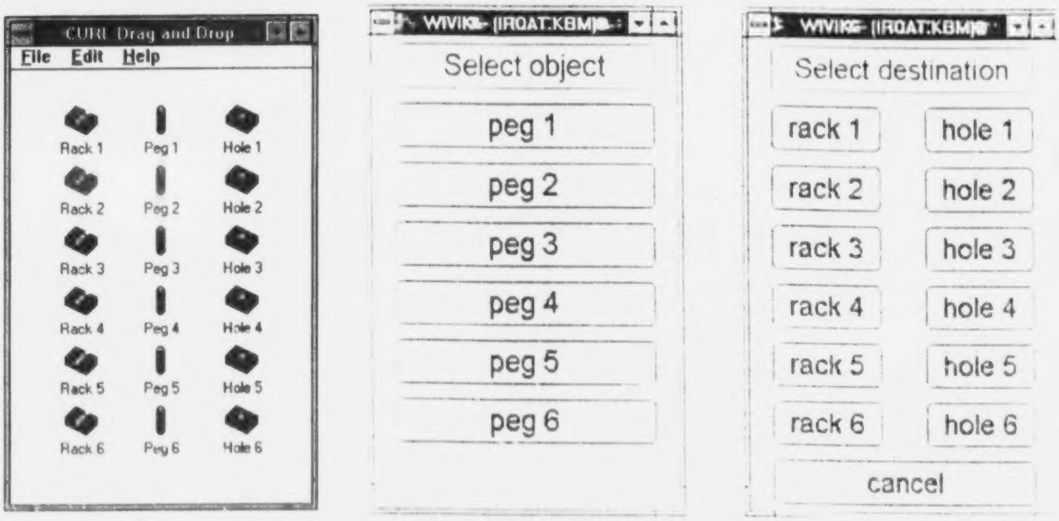
CURL Drag and Drop
File Edit Help
Rack 1
Peg 1
Hole 1
Rack 2
Peg 2
Hole 2
Rack 3
Peg 3
Hole 3
Rack 4
Peg 4
Hole 4
Rack 5
Peg 5
Hole 5
Rack 6
Peg 6
Hole 6
WiViK - (IRQAT.KBM)
Select object
peg 1
peg 2
peg 3
peg 4
peg 5
peg 6
WiViK - (IRQAT.KBM)
Select destination
rack 1
hole 1
rack 2
hole 2
rack 3
hole 3
rack 4
hole 4
rack 5
hole 5
rack 6
hole 6
cancel

Figure 1. Visual elements of the user interfaces

of rehabilitation robot technology. Alternative commercial user interfaces were also evaluated to facilitate a comparison of the current interface technologies. The Windows Visual Keyboard (WiViK) Scan 2.1 was used, both with a pointing input device and with a single switch input device [5]. The Voice Pilot utility from the Microsoft Windows Sound System 2.0 was also employed. This utility provides keystroke emulation using discrete utterance speaker dependent speech recognition.

The trial participants were invited to perform a cognitively simple task which involved the transfer of pegs between holes and racks in a specified sequence. This task was based on that used within the Interactive Robot Quantitative Assessment Test (IRQAT) [6]. Each peg transfer was performed using a pre-programmed CURL procedure to command an unmodified RTX robot arm. The task was repeated four times by each participant, once for each of the four user interfaces. None of the trial participants were able to perform the task unaided.

Each participant selected an appropriate pointing device with which to interact with the prototype iconic interface and the WiViK interface. The button of a IBM-compatible games port joystick was used for switch input to the WiViK interface. Default interface configuration parameters were used wherever possible. Voice Pilot was trained using three examples of each valid utterance. Templates which were found to be unreliable were retrained as necessary. Visual elements of the user interfaces are shown in figure 1. In the case of the iconic interface, peg transfer was initiated by dragging one of the peg icons and dropping it over a rack or hole icon. With the WiViK interface, the user first selected a peg object. The macro keyboard was then replaced by a second keyboard from which a rack or hole destination was selected. Appropriate utterances were displayed by the Voice Pilot interface as a command sentence was formed.

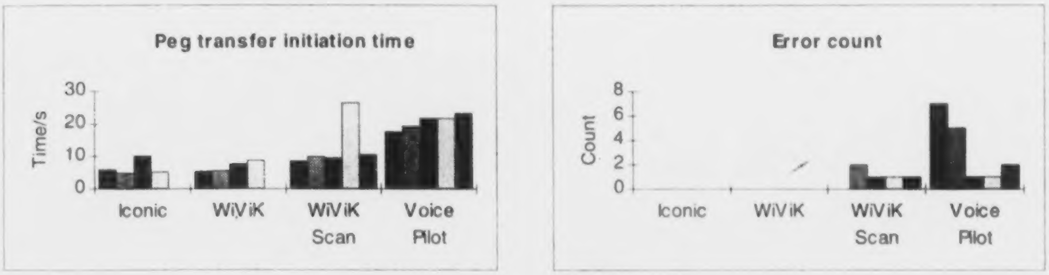

Figure 2. Interface evaluation results

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RESULTS

A questionnaire was completed by each participant at the conclusion of the trial. The questionnaire invited comment on the relative merits of each user interface under evaluation. The standard CURL log facility was used to record the time at which each interaction with the user interface occurred. The resulting log file was analysed to extract the time taken to initiate each peg transfer and the number and nature of any user errors. Those timings which were clearly in error due to interruptions in the evaluation procedure were discarded. The mean values of the remaining data are presented graphically in figure 2. A different shading pattern is used to represent the data of each trial participant.

Four out of the five trial participants stated that the iconic interface was both the most easy to understand and their interface of preference. These participants used a variety of pointing devices including a mouse, a trackball and a headmouse. The other participant was unable to use the iconic interface due to input device compatibility problems. No errors were made by any of the users when working with either the iconic interface or the WiViK interface in conjunction with a pointing input device. Errors were made when using WiViK Scan with a switch input device. The incidence of these errors was reduced as the users became more accustomed to the scanning speed. Command errors occurring with the Voice Pilot interface were due entirely to misrecognition of utterances. The limited duration of each trial session did not permit this interface to be fully optimised. However, the potential benefits of this form of interaction were evident to the majority of trial participants.

CONCLUSIONS

The results indicate that the prototype iconic interface is an acceptable and efficient interface for robot command. The continuous representation of objects and actions of interest was assessed to be beneficial by all participants. They also appreciated the use of icons to reinforce the meaning of each object and the ability to replicate the spatial relationships of objects within the interface.

Further work is necessary to extend the flexibility of the iconic interface for use with more complex robotic workstations. There is also potential for the use of iconic interfaces in conjunction with switch input devices. Extended trials of the existing prototype interface are planned using the RAID2 robotic workstation [7] within an office environment.

ACKNOWLEDGEMENTS

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SENSOR-BASED SHARED CONTROL OF A REHABILITATION MANIPULATION SYSTEM

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ABSTRACT

This paper describes the implementation and evaluation of sensor-based shared control algorithms in a rehabilitation manipulation system. Quantitative and qualitative results of user trials with the system are presented, and the implications of these results are discussed.

BACKGROUND

The goal of this research was to investigate strategies which would enable a person with a severe physical disability to operate a general purpose, robotic manipulation aid in an undefined environment.

Currently available robotic manipulation aids operate in direct or supervisory control modes. In a supervisory control mode, the environment must either be well-defined or it must be possible to obtain information about the environment autonomously. In a direct control mode the operator is responsible for all knowledge and perception of the environment, as well as all motion of the manipulator. Manipulation aids designed for use in undefined environments generally operate under direct control. Such aids have largely been rejected by potential operators due to the difficulties involved in executing a complex motion in a direct control mode [1].

In this research, strategies in sensor-based shared control which provide an intermediate level of autonomy to those of direct and supervisory control strategies have been identified. This approach is desirable both to allow task execution in undefined environments by taking advantage of the cognitive and perceptive skills of the operator, and to give the operator the sense that the manipulator can be used as an extension of him or herself. A behaviour-based architecture was used to implement the shared control strategy [2]. Sensor-based algorithms are used to modify the manipulator trajectory based on the current state of the environment, and the task being executed. The algorithms are highly configurable to the hardware system being implemented, and/or to the tasks which will be undertaken. The integration of the shared control algorithms with the Cambridge University Robot Language (CURL) [3] and their subsequent evaluation is discussed in the following sections.

CURL is robot-independent and operates in the Windows environment. Kinematics and communication sub-systems for specific robotic devices are implemented using a CURL Device Driver (CDD) which is linked to CURL as a Dynamic Link Library (DLL). When using the CURL direct control mode, the operator has continuous control of a single axis of the manipulation system using any Windows compatible input device. Because the goal of a motion is not explicitly known, when using the shared control strategy it is necessary for the operator to define interactively whether a transport or grasping motion is being undertaken. This area has much room for development, particularly with regards to which axes are controlled and how choices are presented in CURL.

IMPLEMENTATION OF SHARED CONTROL

The shared control algorithms are contained in a device-independent module called the trajectory modification function (TMF). Extensive initialisation of parameters defining the number, orientation and significance of sensors mounted on the robot is necessary before the TMF can be used with a specific hardware system. Once configured, the module interacts with the primary trajectory generator to determine how the manipulator trajectory should be modified. For the purpose of integrating the shared control algorithms with CURL, the TMF has been implemented in the form of a DLL.

Figure 1 depicts the way in which the shared control algorithms are integrated with the standard CURL direct control mode. The operator chooses the movement type (transport or grasping) and the movement axis. The TMF is then initialised with the appropriate task-oriented parameter set. Robot-specific kinematics and coordinate transformations to the TMF sensor-coordinate frame are calculated in the CDD. The desired movement trajectory is then modified by the TMF using the sensor-based

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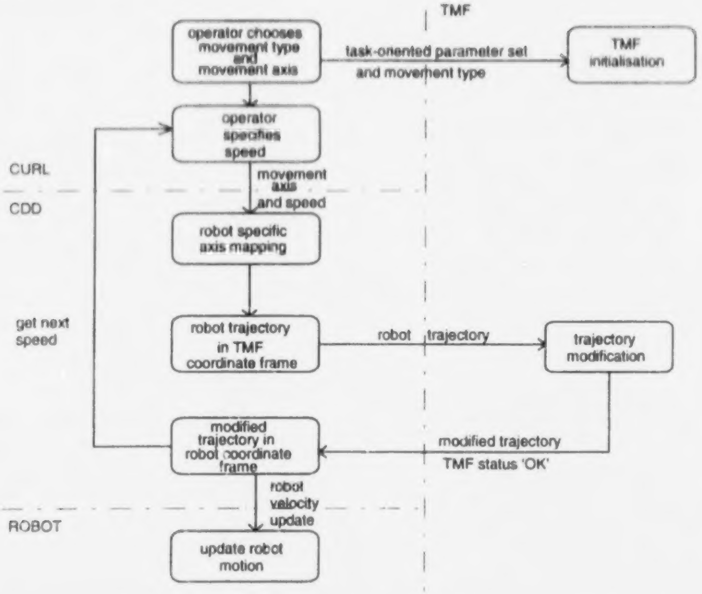
TMF
operator chooses movement type and movement axis
task-oriented parameter set and movement type
TMF initialisation
operator specifies speed
CURL
CDD
movement axis and speed
robot specific axis mapping
get next speed
robot trajectory in TMF coordinate frame
robot trajectory
trajectory modification
modified trajectory in robot coordinate frame
modified trajectory
TMF status 'OK'
robot velocity update
ROBOT
update robot motion

Figure 1. Integration of the TMF with the CURL direct control mode

shared control algorithms, and control is returned to the CDD. The modified trajectory is transformed to the desired robot co-ordinate frame, and the robot velocity is updated. The operator-specified speed is then updated in CURL, and this cycle continues until the operator chooses to stop the motion by discontinuing the input. Motion can subsequently be continued on the same axis, or a new axis and/or movement type can be selected.

The hardware set-up used for the system implementation consisted of an RTX robot with an IMP8 transputer-based control board, eight infrared sensors placed on the standard RTX gripper to provide object proximity information, and a 386DX PC to run the robot control software. An analogue joystick was used as a pointing device for computer interfacing purposes and to control the velocity of the robot along a single axis, as specified in the CURL direct control window.

In the CURL direct control window, nine possible movement axes were provided. These were: Cartesian motion on the world frame x, y and z axes; Cartesian motion on the tool frame x, y, and z axes; pitch; gripper width and yaw. Using the analogue joystick, the operator specified the speed of the manipulator along the chosen movement axis. In the shared control mode, the primary trajectory specified by the operator using the CURL direct control modes was modified by the sensor-based trajectory modification algorithms.

In addition to the direct control modes, a number of CURL procedures which caused the robot gripper to point from a home position to the approximate location of objects in the environment were provided.

EVALUATION

For the purpose of evaluating the shared control algorithms ten able-bodied people were asked to perform a simple task once with the trajectory modification algorithms (shared control), and once without (direct control). The order in which the shared and direct control modes were used was varied in order to minimise the effects of learning in the evaluation results

An evaluation task which was relevant to the daily lives of the operators was desired in order to assess the performance of the system in a realistic environment. In addition, it was felt that the subjects would be better able to plan the actions of the manipulator when performing a task which was familiar to them. According to surveys of user task priorities [4], one task which operators would consider performing with a robotic manipulation aid is the preparation of a hot drink. Thus, the task of making a cup of tea was chosen for these evaluations. Due to practical considerations, real water and teabags were not used in the task; a number of wooden blocks were used as substitute objects.

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RESULTS

CURL generates a log file which allows each control action of the operator to be recorded. In these evaluations, the time at which each procedure was invoked, and the times at which movement along each of the direct control axes were initiated and terminated were recorded. This information was used to calculate: the total time taken to complete the task; the number of modes required to complete the task (the sum of the number of manipulator-level control modes selected in the CURL direct control window, and the number of procedures used); the total amount of time spent in manipulator-level control modes; the number of manipulator-level control modes used; and the average time spent per manipulator control mode. Manipulator control modes refer to those modes in which the operator generated the primary trajectory of the manipulator using the joystick. The average results for the ten subjects are shown in Figure 2.

The results of these trials indicate that the performance of this task was improved through use of the sensor-based trajectory modification algorithms. On average, the time taken to complete the task was reduced, as were the total number of modes used and the number of manipulation modes used. The time spent per manipulation mode was increased, indicating that fewer fine motions were used, and the time spent in manipulation modes was decreased.

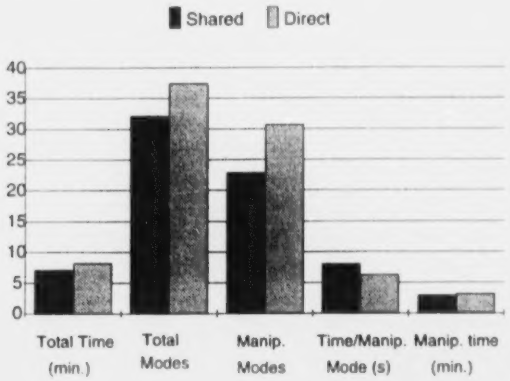

Figure 2. Results of the evaluation of the trajectory modification algorithms.

DISCUSSION

Some differences in task performance and the strategies adopted to complete the task are expected for operators with disabilities. In particular, operators with disabilities may not be capable of fine control motions, and mode changes may require more effort and time. Therefore, in these evaluations, the use of fewer fine control actions, as measured by the average amount of time spent per manipulator mode, and the use of fewer manipulator modes to complete a task are significant. In addition, the use of fewer total modes is important, but reflects the quality of the interface as well as that of the trajectory modification algorithms.

In the evaluation task, the shared control algorithms were perceived by the operators to be most useful in aligning objects in the robot gripper prior to grasping. The transport portions of the task (e.g. moving the water to the cup) were not significantly altered by the use of the shared control algorithms because the environment used for the trials was static, and very little object avoidance was necessary.

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TOWARD A MULTIMODAL ENVIRONMENT FOR LEARNING ROBOT MANIPULATION BY PEOPLE WITH SEVERE DISABILITIES

Mounir Mokhtari[1], Agnès Roby-Brami[2]

ABSTRACT

The project is to find out a method of analyzing motors capabilities of disabled people. We are working on a 3D method for measuring motor capabilities when acting on different Man/Machine interfaces by the use of the Spatial Tracking System (Polhemus Fastrack). We have developed a software program to record the 3D movement and represent the trajectory on-line of each sensors and the movement on line in 3D. An off-line analysis is also provided. This paper describes a method under development which consist of using Polhemus sensors when manipulating an arm robot and representing the trajectory of the working point on-line during the movement. 3D audioguided end effector movement when reaching a target in space is also provided. The ultimate aim of this project is to improve the visual and audio feedback when applying robotics technology to assist people with severe disabilities in the task of learning to operate an arm robot.

KEYWORDS

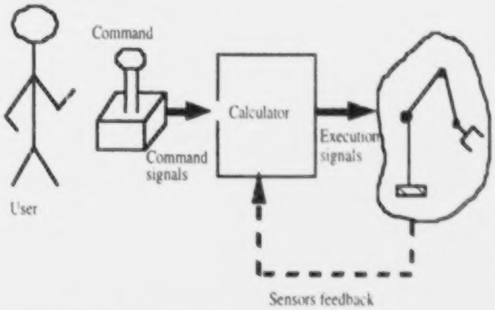
Multimodal Learning Environment, AudioGuided Movement, Motor Capabilities Analysis.

INTRODUCTION

The application of technological assistance to the needs of people with reduced motors abilities is available in four main area: mobility, by the use of powered wheelchairs, home control environment systems, manipulation, where a lot of robotics system appears this last decade, and alternative communication. The problem is that a great number of different items of electronic equipment, made by different companies, are presented to an individual, and each one is furnished by it's own specific input device. So the user, with severe motor disabilities, is confronted with multiple man/machine interfaces. Some integrated systems to have access to the areas described above has been developed [2]. But the main problem is the lack of a method to analyze the needs of each individual in term of technological assistance and to provide general guidelines so that the different companies will take it into account for the development of future products.

MANIPULATION BY MOTOR COMMAND ANALYSIS

We are using movements recording methods to analyze the way a disabled individual is acting on the input device of a technological assistance system. An expert user is capable of performing programmed movement to reach the target [6]; we can also analyze the errors that occurs when the movement is done by a novice user. This type of methods must permit to analyze the origin of problems faced by disabled users within the use of direct manipulation interfaces. Consequently, it's necessary to compare the command gesture realized by the user on the input device with the displacement of the robot end effector.



HARDWARE CONFIGURATION

The measurement tool is a spatial tracking system (STS) developed by Polhemus (Fastrack) which is based on the use of up to four electromagnetic sensors. It's permit to measure the position (X, Y, Z) and the orientation (yaw, pitch and roll) of each sensor according to a transmitter which represent the fixed cartesian coordinate at a maximum sampling frequency of 120 Hz. A high speed serial link insure the connection between the computer and the STS. The software is developed on a personal computer using the Borland C++ on Windows. A first version has been developed under DOS with Turbo C and now we are rewriting the software on Windows to improve the graphics interface to make it more convivial for non experimented users. The sounds used in audioguiding movements are generated by a standard SoundBlaster audio card.

VIRTUAL CAMERA IMPLEMENTATION

The objective is to represent the 3D position of the STS sensors, or the object on which the sensor is fixed , for example the human hand and the end-effector, on the screen. The solution adopted is to create a virtual camera which permits the conversion a 3D image of the point position on a projection screen [4].

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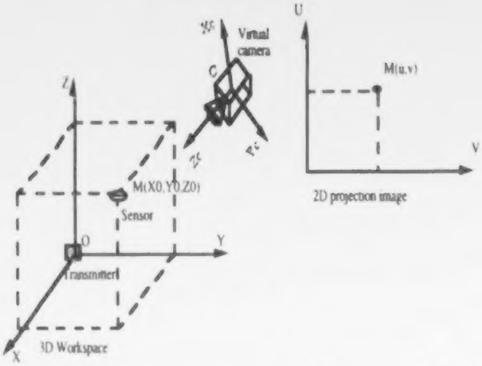
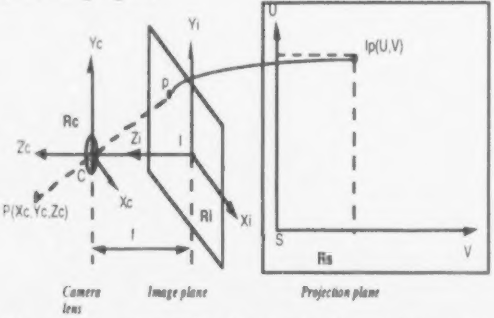


The direct consequence of this method is the visualization of the trajectory of the sensor under different angles by adjusting the position and the orientation of the virtual camera according to the fixed cartesian coordinates of the transmitter.

The geometrical model of the camera is defined by a certain number of parameters; the intrinsic parameters based on the internal model and the extrinsic parameters which are linked to the external model. The camera permits the projection of a 3D point of the workspace on 2D workspace, in other words performing the transformation from a metric coordinates to an image coordinate (i.e. pixels). The internal model is illustrated by the following figure.



We suppose that P(Xc,Yc,Zc) is the position, at a given time, of the sensor according to camera system of coordinate Rc. The coordinate systems Ri is fixed on the image plane and Rs on the projection plane. The transformation from Rc to Rs is defined as follow:

$$\begin{pmatrix} Zc.U \\ Zc.V \\ Zc \end{pmatrix} = \begin{pmatrix} -f.eu & 0 & gu & 0 \\ 0 & -f.ev & gv & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} * \begin{pmatrix} Xc \\ Yc \\ Zc \\ 1 \end{pmatrix}$$

f: focal of the camera
eu and ev: factors of the ladder in pixel/m
gu and gv: the translation of the origin translation of the axis U and V

Before processing the internal model to display the different position on the screen, it's necessary to perform a coordinate transformation to move from the fixed system coordinate of the transmitter (i.e. Ro) to the camera system of coordinate (i.e. Rc).

$$\begin{pmatrix} Xc \\ Yc \\ Zc \\ 1 \end{pmatrix} = \begin{pmatrix} R11 & R12 & R13 & Ox \\ R21 & R22 & R23 & Oy \\ R31 & R32 & R33 & Oz \\ 0 & 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} Xo \\ Yo \\ Zo \\ 1 \end{pmatrix}$$

where Rij, defined below, represent the elements of the rotation matrix according to each axis: Rot(3,3) = Rot(z,Θ).Rot(y,φ).Rot(x,ψ) where Θ, φ and ψ are the Euler angles given by the STS.

R11= Cos(Θ).Cos(φ)
R12= Sin(Θ).Cos(φ)
R13= -Sin(φ)
R21= Cos(Θ).Sin(φ).Sin(Ψ)-Sin(Θ).Cos(Ψ)
R22= Sin(Θ).Sin(Ψ).Sin(φ)+Cos(Θ).Cos(Ψ)
R23= Cos(φ).Sin(Ψ)
R31= Cos(Θ).Sin(φ).Cos(Ψ)+Sin(Θ).Sin(Ψ)
R32= Sin(Θ).Sin(φ).Cos(Ψ)-Cos(Θ).Sin(Ψ)
R33= Cos(φ).Cos(Ψ)

The position of the camera according to the fixed cartesian coordinate is defined by the vector (lx,ly,lz). The translation vector (Ox,Oy,Oz) which correspond to the position of the origin 'O' according to Rc is defined by :

$$\begin{pmatrix} Ox \\ Oy \\ Oz \end{pmatrix} = \begin{pmatrix} R11 & R12 & R13 \\ R21 & R22 & R23 \\ R31 & R32 & R33 \end{pmatrix} * \begin{pmatrix} lx \\ ly \\ lz \end{pmatrix}$$

lx, ly, lz, Θ, φ and ψ are the external parameters of the camera.

AUDIOGUIDING METHOD USING STS

The perspective of audioguiding is to help the learning of complex motor commands in the field of assistive robotics devices. One sensor was fixed on the back of the hand and another one represented the target. We put a third sensor on the forehead to get the movement of the head during the experimentation. We have tested two methods on normal blindfolded subjects[5]: In the first one, the sound frequency varied as a function of the distance between the hand and the target and in the second one we have added the variation of the amplitude of the sound as a function the discrepancy angle between the actual movement and the target direction. The movement of the 3 sensors is displayed on-line on the screen.

To get a linearity in the variation of the sound we have to consider an non-linear frequency function. The position of the target according to the position of the hand is defined by the vector $\vec{V}$ and the frequency is given by :

$$Frequence = \lambda . EXP(\mu . \left\| \vec{V} \right\|)$$

λ(equal to 1124.6) and μ(equal to -2.42) are parameters defined by the frequency bandwidth which was delimited from 30 to 1000 Hz and by the variation of the distance from the target of 1.5 meter. A ray of 5 cm around the target was defined to represent the success reaching area.

In the second method we added to the variation of the frequency according to the target distance the amplitude parameter. When the movement is on the direction of the target the amplitude of the sound is maximum otherwise it's attenuated according to the discrepancy angle.

We have considered, as with the frequency function, an exponential variation of the amplitude:

$$Amplitude = 194.54 * EXP(0.26 * Angle)$$

The instantaneous direction vector $\vec{U}$ is compared to the target direction $\vec{V}$ continuously

$$Angle = \vec{U} \cdot \vec{V} / \left\|\vec{U}\right\| \cdot \left\|\vec{V}\right\|$$

The sound is not permanent: it's sended to feedback only when the subject is moving his hand, so we have fixed a threshold velocity at 8cm/s.

FIRST STAGE EVALUATION

Five non-disabled individuals have participated to the experimentation of the audioguiding methods[5]. The subjects had the instruction of reaching the target by guiding following high notes sounds. Ten targets has been randomly chosen for each method.

The two methods permitted to the subject to reach the target without the control of the eyes, usually before the time-out (1.30 minutes). In opposition to our start hypothesis, the first method of varying the frequency according to the distance appears to be more efficient than the second one.

CONCLUSION

Interaction analysis between the disabled user and the man/machine interfaces will permit to point out the problems encountered when using technological assitive devices. This paper describes a study, under development, which consists of creating a learning environment using both visual and audio feedback when acting on a robotics system. The results obtained by the two audioguided movement methods are not very consequent for the second one which consist of adding an amplitude variation with the frequency variation. We plane to improve this method by redefining on-line the sounded workspace with the use of a geometric cone fixed to the target. We are also investigating the use of the M3S communication bus [1] which permit to interconnect different input/output devices on the same wires. This will help us to check the type of data emitted by an input, for example a joystick, and the result translated on the movement of the end-effector of an arm robot, for example Manus II robot.

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MULTIMODALLY CONTROLLED INTELLIGENT ASSISTIVE ROBOT

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Abstract

The Multimodal User Supervised Interface and Intelligent Control (MUSIIC) project is working towards the development of an assistive robotic system which integrates human-computer interaction with reactive planning techniques borrowed from artificial intelligence. The MUSIIC system is intended to operate in an unstructured environment, rather than in a structured workcell, allowing users with physical disabilities considerable freedom and flexibility in terms of control and operating ease. This paper reports on the current status of the MUSIIC project.

Background

One of the most challenging problems in rehabilitation robotics is the design of an efficient control mechanism that allows users with motor disabilities to manipulate her environment in an unstructured domain. Rehabilitation robotics research literature describes many demonstrations of the use of robotic devices by individuals with disabilities [1, 2]

Prototype interfaces have taken two approaches to achieving effective use by individuals with disabilities. Some are command oriented where the users activate the robot to perform pre-programmed tasks [3, 4]. In contrast, there have been a number of projects in which the user directly controls all the movements of the manipulator much like a prosthesis [5, 6].

While direct control allows the user to operate in an unstructured environment, problems such as physical and cognitive load on the user, the requirement of good motor dexterity of the user and many other real-time perceptual and motor requirements preclude an efficient and useful assistive robot.

Command based systems also pose significant problems [7]. While modern speech recognizers provide access to large numbers of stored commands, effective command of a robot will require use of more commands than is reasonable for the user to remember. As the number of possible commands grows, the human/machine interface becomes increasingly unmanageable. Crangle and Suppes propose greatly expanding the capability of the robot to not only recognize spoken words, but also understand spoken English sentences [8].

A different approach to command-based robot operation was proposed by Harwin et al [9]. A vision system viewed the robot's workspace and was programmed to recognize barcodes that were affixed on each object and used the barcodes to determine the location and orientation of every item. While this was only successful within a limited and structured environment, it did demonstrate the dramatic reduction in *machine intelligence* that came by eliminating the need for the robot to perform object recognition and language understanding.

At the other extreme of robot control are the completely autonomous systems that perform with effectively no user supervision, the long elusive goal of AI, robotics and machine vision communities. Unfortunately, this goal seems far from practical at this point, although many important incremental advances have been forthcoming in the past decades. Furthermore, absolute automation poses a set of problems stemming from incomplete *a priori* knowledge about the environment, hazards, insufficient sensory information, inherent inaccuracy in the robotic devices and the mode of operation.

Objective

Therefore, what one should strive for is a synergistic integration of the best abilities of both *"humans"* and *"machines"*. Humans excel in creativity, use of heuristics, flexibility and "common sense', whereas machines excel in speed of computation, mechanical power and ability to persevere. While progress is being made in robotics in areas such as machine vision and sensor based control, there is much work that needs to be done in high level cognition and planning. We claim that the symbiosis of the high level cognitive abilities of the human, such as object recognition, high level planning, and event driven reactivity with the native skills of a robot can result in a human-robot system that will function better than both traditional robotic assistive systems and autonomous systems.

Our MUSIIC strategy overcomes the limitations of previous approaches by integrating a multimodal RUI (Robot User Interface) and a semi-autonomous reactive planner that will allow users with severe motor disabilities to manipulate objects in an unstructured domain. The multimodal user interface is a speech and deictic (pointing) gesture based control that guides the operation of a semi-autonomous planner controlling the assistive robot.

MUSIIC utilizes a stereo-vision system to determine the three-dimensional shape and pose of objects and surfaces which are in the environment, and provides an object-oriented knowledge base and planning system which superimposes information about common objects in the three-dimensional world [10, 11]. This approach allows the user to identify objects and tasks via a multimodal user interface which interprets her deictic gestures and speech inputs. The multimodal interface performs a critical disambiguation function by binding the spoken words to a locus in the physical work space. The spoken input is also used to supplant the need for general purpose object recognition. Instead, three-dimensional shape information is augmented by the user's spoken word, which may also invoke the appropriate inheritance of object properties using the adopted hierarchical object-oriented representation scheme.

Method

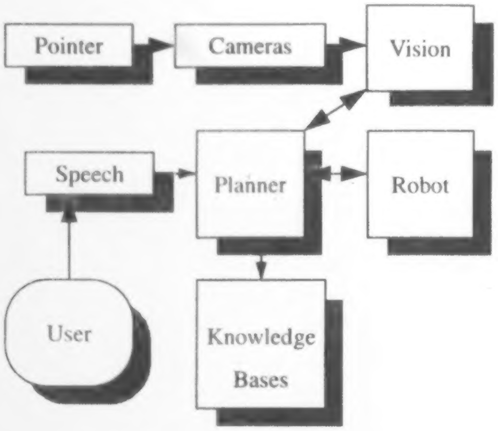

Figure 1: System Configuration

The previous sections lead naturally to a description of the essential components of the MUSIIC system [Figure 1]. We require a ***planner*** that will interpret and satisfy user intentions. The planner is built upon ***object oriented knowledge bases*** that allow the users to manipulate objects that are either known or unknown to the system. A ***speech input*** system is needed for user inputs, and a ***gesture identification*** mechanism is necessary to obtain the user's deictic gesture inputs. An ***active stereo-vision*** system is necessary to provide a snap-shot of the domain; it returns object shapes, poses and location information without performing any object recognition. The vision system is also used to identify the focus of the user's deictic gesture, currently implemented by a laser light pointer, returning information about either an object or a location. The planner extracts user intentions from the combined speech and gesture input. It then develops a plan for execution on the world model built up from the *a priori* information contained in the knowledge bases, the real-time information obtained from the vision system, the sensory information obtained from the robot arm, as well as information previously extracted from the user dialog. Prior to execution, the system allows the user to preview and validate the planner's interpretation of user intentions via a 3-D graphically ***simulated environment*** [12]. Figure 2 shows the actual system set-up.

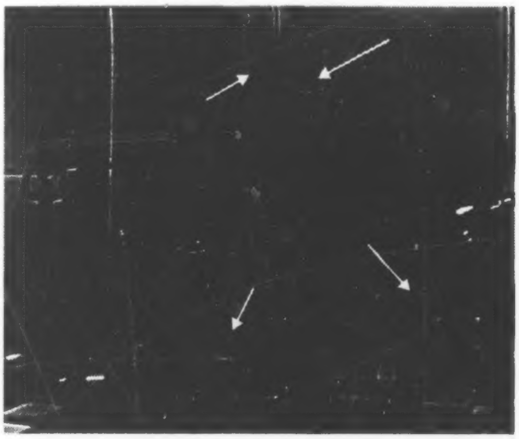

Figure 2: Physical set-up

Result and Illustration

The current operational implementation of MUSIIC is able to manipulate objects of generic shapes at arbitrary locations. A set of robot control primitives are used to build up higher level task commands with which the user instructs the assistive robot. The robot primitives include approaching, grasping and moving an object amongst others. The vision system first takes a snap shot of the domain and returns to the planner object sizes, shapes and locations. This information is then combined with the knowledge base of objects to model the workspace in question. The user then points to objects using a laser light pointer while verbally instructing the robot to manipulate an object.

For example, the user may say "`Put that here`", while pointing at an object as she says "`that`" and pointing to a location as she says "`here`". First, the combined gesture and verbal deictic is interpreted by the planner based on information extracted from the

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vision system as well as the object knowledge base. The planner then uses the plan knowledge base to approach and grasp the object and then move the object to the desired location.

In addition to high level commands as illustrated above, the user is also able to instruct the robot at a lower level, by commands such as "`move there`", "`open gripper`", "`move down`", "`close gripper`", "`move here`" to obtain the same functionality as the "`move that here`" instruction.

Discussion

While MUSIIC is still very much a work in progress, the current test-bed implementation has amply demonstrated the flexibility in use of an assistive robot achievable by our multimodal RUI built on top of an intelligent planner. Work is continuing in fleshing out the complete object hierarchy that will allow the planner to plan tasks at any level of specialization, from objects about which nothing is known except what the vision system returns to objects which are well known, such as a cup often used by the user. The reactive component is also nearing completion. Reactivity will be achieved in two ways: An autonomous runtime reactivity will be obtained through sensor fusion and a human centered reactivity will be used where the user can take over the planning process when the planner fails to make correct plans as a consequence of incomplete information or catastrophic failures. The user will engage in a dialog with the system, either to update the knowledge bases or to perform plan correction or editing.

Conclusion

Human intervention as well as an intelligent planning mechanism are essential features of a practical assistive robotic system. We believe our multimodal RUI is not only an intuitive interface for interaction with a three-dimensional unstructured world, but it also allows the human-machine synergy that is necessary for practical manipulation in a real world environment. Our novel approach of gesture-speech based human-machine interfacing enables our system to make realistic plans in a domain where we have to deal with uncertainty and incomplete information.

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METHOD OF CONTROLLING A/K PROSTHESIS FOR ASCENDING WITH DISABLED SIDE HIP JOINT TORQUE

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ABSTRACT

This paper deals with the controlling method of A/K prosthesis which enables lower limb amputees to ascend the staircase. As conventional A/K prostheses are designed for walking on the level surface, the disabled persons wearing them have been compelled to walk on stairs with unnatural posture. The construction of powered A/K prostheses requires not only the prosthesis mechanism but also its controlling method. Measuring the axial force and moment acting on the socket that is the human-machine-interface during walking with the six axis force-moment sensor, the torque of disabled side hip joint was calculated. We devised a controlling method using this torque for a feedback signal. The results of clinical walking experiment indicated that the subjects wearing the A/K prosthesis could walk with joint angle patterns similar to those in a normal subject. Furthermore, with the results of the inverse dynamics analysis, the amputee subject generated a torque and power pattern at his disabled side hip joint similar to that in the normal subject.

BACKGROUND

To disabled persons who lost their lower limbs at the thigh level, A/K prosthesis is an indispensable assistive system for their daily activities. However the function of the conventional A/K prostheses is limited, because they do not enable the amputee to walk on a step or staircase.

To solve this problem, the author had developed a multi-functional A/K prostheses. It generated enough power at the knee joint for stair walking(1)(2). This type of powered A/K prosthesis has not been developed with some exceptions. Active artificial Leg was one of them. That had been developed by one of the National Research and Development Programs for Medical and Welfare Apparatus in Japan. The controller of this leg receives signals from a foot-switch equipped in the shoe, and starts extending, the knee joint following a preset angle pattern(3).

STATEMENT OF THE PROBLEM

In the development of power artificial limbs, not only the development of mechanisms but also the controlling method which drive it adequately are important subjects. Because, if it is not controlled appropriately, the powered A/K prosthesis may injure the amputee or people around him/her with its power.

The aim of this study is to construct the new controlling method which has the following function. Amputees can control the movement of their A/K prosthesis by with moving the hip joint of the disabled side same as the normal side, without any special unnatural operation to drive the prosthesis.

RATIONALE

Amputees drive their A/K prostheses with their hip joint of the disabled side. In this study, the author considered a new controlling method using a hip joint torque of the disabled side as a controlling signal. With this signal, a voluntary and natural controlling method will be accomplished.

DESIGN AND DEVELOPMENT

MECHANISM OF THE A/K PROSTHESIS

The basic specification of the powered A/K Prosthesis is that it can generate enough power to the joint when it is needed. Figure 1 shows the basic mechanism which contains two systems; a closed hydraulic circuit system and an electronic power system. The former consisted of the piston-cylinder systems linked with movements of ankle and knee joints, and the latter consisted of battery, DC-motor and ball-screw to drive the knee joint. With these two systems, necessary power could be transmitted to the knee joint immediately during stairs ascending(1)(2).

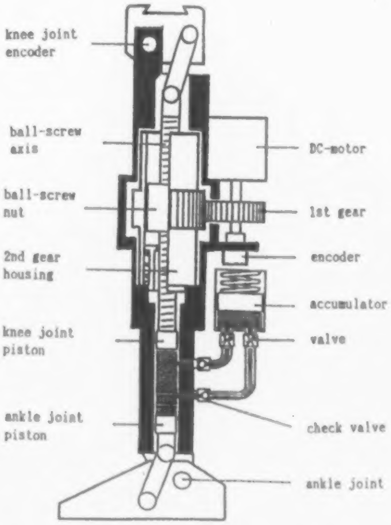

Figure 1. Basic Mechanism of Multi-functional A/K Prosthesis

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Results of an inverse dynamics analysis of gaits carried out by normal subjects showed the two phases of driving the knee joint from the external electric power supply.

1. when the knee joint extends to push up the upper body, during the stance phase.
2. when the knee joint flexes to pull up the toe of the prosthesis not to touch the edge of the staircase.

CONTROLLING METHOD

To control the prosthesis with the torque of the hip joint of the disabled side, it was necessary to calculate the torque in real-time. So the six axes force-moment sensor (NITTA, UFS-4520A) was equipped between the socket and the knee joint of the A/K prosthesis(4). Figure 2 shows the sensor mounted on top of the prosthesis. Figure 3 shows the two dimensional link model on sagittal plane containing the information gathered by the sensor.

The torque acting on each joint was represented by eq.[1]-[3].

$$\overrightarrow{M_H}=\overrightarrow{M_P}+\overrightarrow{H_P}\times\overrightarrow{f_P}+(m_{H1}\overrightarrow{HG_{H1}}-m_H\overrightarrow{HG_H})\times\overrightarrow{g}$$
$$-m_{H1}\overrightarrow{HP}\times\ddot{\overrightarrow{G_{H1}}}+(J_H-J_{H1})\ddot{\overrightarrow{\theta_H}}\cdots\cdots\cdots\cdots [1]$$
$$\overrightarrow{M_K}=\overrightarrow{M_P}+\overrightarrow{KP}\times\overrightarrow{f_P}+m_{H1}\overrightarrow{KG_{H1}}\times\overrightarrow{g}$$
$$-m_{H1}\overrightarrow{KP}\times\ddot{\overrightarrow{G_{H1}}}-J_{H1}\ddot{\overrightarrow{\theta_H}}\cdots\cdots\cdots\cdots [2]$$
$$\overrightarrow{M_A}=\overrightarrow{M_P}+\overrightarrow{AP}\times\overrightarrow{f_P}+(m_{H1}+m_K)\overrightarrow{AG_{H1}}\times\overrightarrow{g}$$
$$-m_{H1}\overrightarrow{AP}\times\ddot{\overrightarrow{G_{H1}}}+m_K\overrightarrow{KA}\times\ddot{\overrightarrow{G_K}}$$
$$-J_K\ddot{\overrightarrow{\theta_K}}-J_{H1}\ddot{\overrightarrow{\theta_H}}\cdots\cdots\cdots\cdots [3]$$

As inertial terms was smaller than other terms, the gravity term and acceleration term can be neglected. So eq.[1]-[3] are transformed into eq.[4]-[6], respectively. As a result, they can be calculated in real-time, and the torque of the disabled side hip joint, MH, can be utilized as a feedback signal.

$$\overrightarrow{M_H}=\overrightarrow{M_P}+\overrightarrow{HP}\times\overrightarrow{f_P}\cdots\cdots\cdots\cdots [4]$$
$$\overrightarrow{M_K}=\overrightarrow{M_P}+\overrightarrow{KP}\times\overrightarrow{f_P}\cdots\cdots\cdots\cdots [5]$$
$$\overrightarrow{M_A}=\overrightarrow{M_P}+\overrightarrow{AP}\times\overrightarrow{f_P}\cdots\cdots\cdots\cdots [6]$$

CLINICAL WALKING EXPERIMENT FOR EVALUATION

Clinical experiments were carried out on two amputees who lost their left thigh. After several trials by them, the trigger torque, MH, that starts the extension of the knee joint was determined to 40[Nm]. This torque is almost equal to that in normal persons. Another trigger compression force, Fz, that starts the flexion of the knee joint was also determined to 100[N]. This force is almost equal o that in normal persons, too.

RESULTS AND DISCUSSION

Figure 4 shows the data on a normal person (left) and these on an amputee (male,aged 27)(right). The upper and lower parts of Fig.4 show the hip joint and knee joint, respectively. The abscissa represents normalized time[%], and 0 and 100[%] mean toe contact. Four domains divided by vertical lines indicate, from left to right, double supported phase, single supported phase, double supported phase and swing phase. The dotted curve and two solid curves show the joint angle, joint torque and joint power, respectively. As to the power curve, the positive value and negative value mean the driving power and breaking power respectively, because the power is a product of torque and angle velocity. These data revealed that the amputee wearing the A/K prosthesis could walk with a joint angle pattern similar to that in the normal subject. Furthermore the results of the inverse dynamics analysis demonstrated that the amputee generated a torque and power pattern at his disabled side hip joint similar to that in the normal subject.

Sequential pictures are shown in Figure 5. Within one hour training, the amputees could master stair walking without the help of his upper limbs.

A foot switch has often been used as a sensor to generate a controlling trigger signal. However, due to the instability of this signal, the movement of A/K prostheses tends to be unstable. The present study demonstrated that the stability of the A/K prosthesis movement was improved greatly by using the the axial force moment as a controlling signal. In fact, the amputee reported that he felt relieved because when he wanted to move the knee joint of the prosthesis it began moving automatically without any delay.

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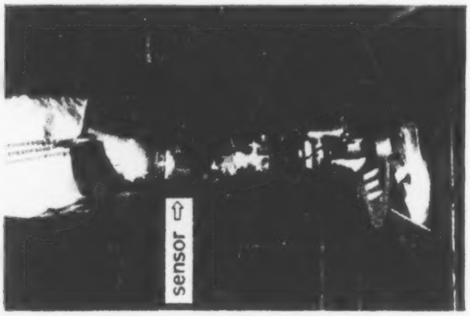


Figure 2. Powered A/K Prosthesis and Sensor

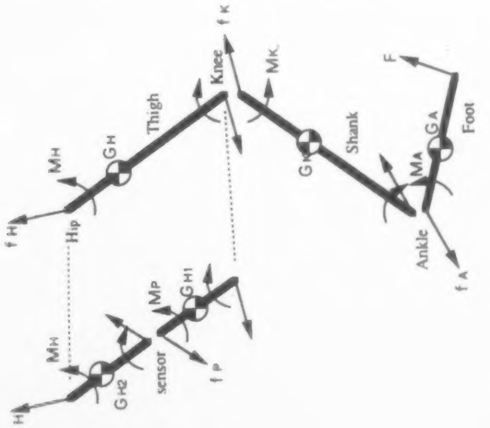
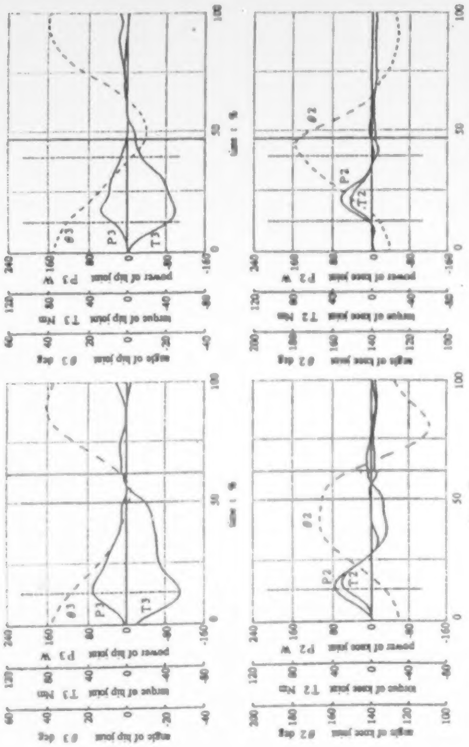

f H
M H
G H2
sensor
f P
M P
G H1
Hip
G H
Thigh
Knee
f K
M K
G K
Shank
M A
G A
Foot
F
Ankle
f A

Figure 3. Link Model of the Lower Limbs



sound person

amputee

Figure 4. Result of Clinical Test

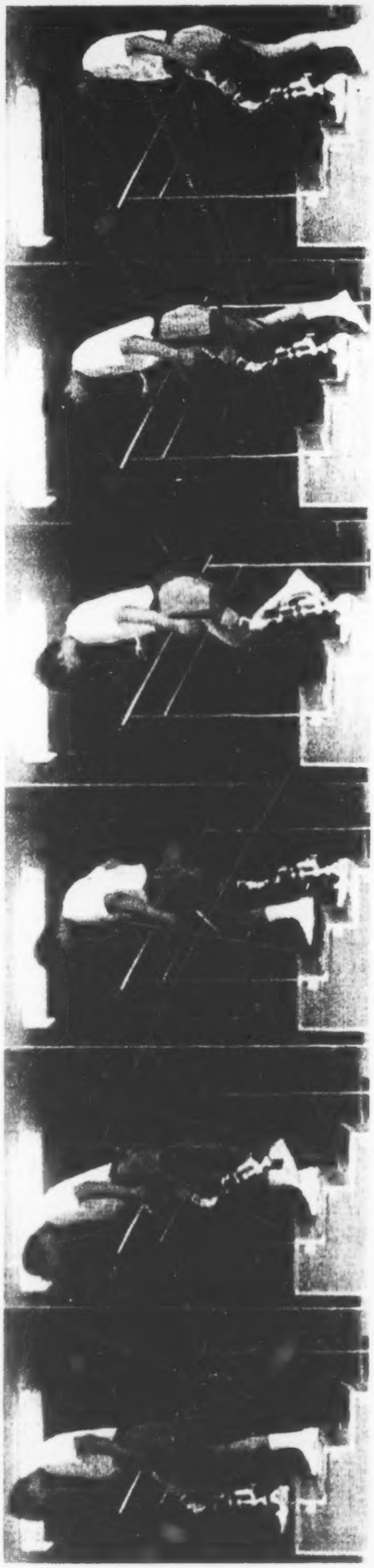


Figure 5. Sequential Pictures of Ascending the Staircase

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Safety Issues for Kinesthetic Interfaces in Assistive Robotics

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ABSTRACT

Kinesthetic displays are mechanical devices that are designed to apply forces and enforce positions at different contact sites on a user under computer control. These devices have great potential, and are finding application in a wide variety of rehabilitation related applications. Examples of these devices include force-reflecting joysticks for wheel-chair control, six degree-of-freedom head-input devices for improved assistive robot dexterity, and haptic displays to aid in the visualization of mathematical surfaces for students with visual impairments. Since a kinesthetic display is effectively a robot which operates in intimate proximity to the user, it is essential that safety issues be taken into consideration in their design and installation so that their many advantages can be enjoyed while presenting minimal risk to the user and their surroundings.

BACKGROUND - SHARING THE WORKSPACE

Traditional uses of robotic systems have involved installing robots in controlled access locations within a manufacturing environment [1]. Safety principles used in manufacturing safety standards for robot installations include making sure that the operator is never in the work envelope of the robot when it is powered up and capable of moving and limiting maximum velocities during maintenance and programming tasks [2]. These constraints can be enforced through a variety of safety techniques such as sensorizing the area around the robot through capacitive and infrared thermal sensing, pressure sensitive floor mats, interlocked gates and other barriers such that when a human enters the area around a robot it is put into safe mode.

This type of controlled access to robot workspaces to ensure safety is in contrast to the requirements for rehabilitation robotic systems [4] such as powered orthoses, dexterous general purpose robots, assistive robots for vocational workstations and feeding robots. In order to be useful, these systems almost inevitably require that the consumer and his/her human associates be inside the robot workspace either intermittently or continuously.

Robots are migrating ever closer to the consumer in the form of kinesthetic force displays. These displays [6] have great potential for educational, entertainment (VR) and high-dexterity input to control assistive robots [5]. Kinesthetic interfaces apply forces and moments at the physical interface between the operator and the haptic display. The contact site for a kinesthetic display may be located on a fingertip, palm of the hand, residual limb or at the head/neck depending on the disability.

We have developed a system incorporating specially modified PerForce™ robot (Cybernet Systems, Ann Arbor, MI) that acts as a kinesthetic master in a master-slave telerobotic test bed. This system has been designed to assist people with severe spinal cord injuries by the use of head-movement and proprioception. The system applies the concept of a virtual headstick interface with extended physiological proprioception (EPP) where the user's head/neck experiences the same forces as the slave in order to make him/her feel as if he were in direct contact with the environment (see Figure 1).

PROBLEM STATEMENT

The ability to have force feedback in the system is a curse as well as a blessing. When properly used and scaled, the forces fed back from the slave manipulator can dramatically improve performance on force constrained tasks such as key-insertion and other activities for daily living. If uncontrolled or improperly limited, the applied forces and moments may represent a potential hazard to the operator or people nearby. We consider possible failure modes leading to excessive forces below.

ADDRESSING SAFETY CONSIDERATIONS FOR BILATERAL KINESTHETIC SYSTEMS.

Bilateral telerobotic systems (see Figure 2) allow forces to flow from the operator to the environment and back from the environment to the operator. Our system, which is a representative of this type of system has a number of possible failure modes that may lead to excessive forces being applied to the operator. By inspection of Figure 2, several possible primary failures modes become apparent including wiring faults in the sensing apparatus of the master or slave robots, structural failure of master/slave robots, failures in the communication channel, software faults and computer hardware failures. Although much care can be taken in engineering these systems, both from a software standpoint, such as using reliable software

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specifications [3] and use of redundant wiring, computing and hierarchical computing architectures and watchdog timers [7] failure in any combination of these subsystems might lead to large and possibly damaging forces being applied to the operator.

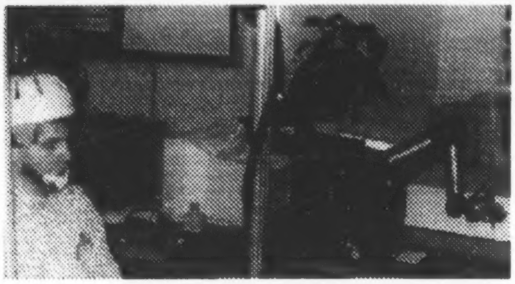

Figure 1: Bilateral Kinesthetic Head-Control of an Assistive Robot

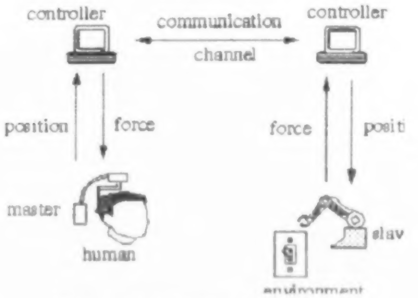

Figure 2: System Components

One obvious approach to increasing force safety is to limit the maximum achievable forces and moments that can be generated by the master kinesthetic display through specification of small motors, or current limiting on power amplifiers. This is an appealing approach, but these limits on motor torques may be contradictory with robot control techniques that increase the bandwidth of kinesthetic displays and improve their usability and functionality through feed-forward control which compensates inertial and frictional effects.

The bilateral kinesthetic control architecture presents unique sources of large forces aside from the primary software/hardware failure modes described above. Due to the bidirectional flow of forces between the master and the slave, collisions with objects in the environment may lead to large impulsive forces on the operator. Oscillations may occur if stability criteria for the system feedback loops are violated due to sensor failure or software failure, which in turn changes system gains. Care can be taken to design control systems for telerobots such that they are unconditionally stable such as through ensuring of passivity of all system components from a control standpoint, but this does not guarantee that the system cannot store and release energy in a fashion which might lead to large forces.

Our system incorporates a number of safety features, such as kinematic singularity avoidance on the slave robot, consistency checking of communication packets, and software integrity checking through the use of a watchdog timer. However in order for it, and other systems incorporating kinesthetic master devices, to benefit user communities and gain user acceptance, it will be important to provide a simple force-safety system which is independent of the complex software/hardware subsystems of bilateral kinesthetic systems.

Ideally, we wish to have a breakaway mechanism which completely frees the user's head from the master in the event of extreme forces or torques; a type of "force fuse."

BIOMECHANICAL CONSIDERATIONS

In order to design a safety feature that will prevent injuries to the user, we must first understand how and why head and neck injuries occur. Once the force and torque limits and the mechanisms of injury are understood, a proper force fuse can be implemented.

Injuries at multiple levels of the spine, head, and neck can occur due to applied external loads or moments. The muscles in this region work to protect against injury, but these muscles are all voluntary. It has been found that the total time to maximum muscle force is on the order of 130-170 ms and is likely to be too long to prevent injury in a surprise impact or moment situation [9]. Therefore, injuries are more likely to occur at some unguarded moment, while muscles are relaxed, and it is unlikely that the operator would have time to react by hitting a kill switch or other de-activating device.

During unexpected impact or torsion, the neck will pass through its normal range of motion and into the stress and trauma ranges with little resistance [10]. Injuries are then more likely to occur at this point because there is a lack of muscle resistance to reduce the momentum of the blow or to increase the time the neck travels through its range of motion.

Although this may be the most vulnerable time for the head, neck and spinal regions, many serious injuries can still occur with the muscles working to resist. This can especially be a problem when the user has a motor disability such as a previous injury which may have lead to a weakened musco-skeletal complex. Some preliminary work has been done in characterization of head-motion limits and maximum reaction forces for subjects with high-level spinal cord injuries [8] which provides a base-line for design specifications via safety-margins. Practically it will be necessary to measure such parameters in a fitting protocol to take into account the unique biomechanical ranges of each user.

DESIGN APPROACH AND DISCUSSION

Taking into consideration the biomechanics of head and neck injury, as well as the application of this device, a number of specifications, or criteria arise. First, the device must be able to release instantaneously, since muscles are most vulnerable in their relaxed stage. Also, it needs to release at the predetermined force and torque limits. Since this may be different for each user, an adjustable strength device would be ideal. The device should have precise and repeatable disengagement properties and not disengage before the proper limits. Finally, dealing with the self-sufficiency issue, the breakaway mechanism should be able to reattach easily under the control of the user. We are currently evaluating 3 different conceptual designs for the force-fuse, a friction based tensioning system which enforces normal forces between two disks with known frictional characteristics, a ski-binding based approach, and an analog electronic force/torque and accelerometer based approach. The expected strengths and weakness of different approaches are briefly summarized in Table 1.

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	Friction	Binding	Analog
Accuracy	medium	high	high
Repeatability	medium	high	high
Durability	high	high	medium
User Reattachable	yes	yes	yes
Reliability	high	high	medium
Weight	high	low	medium
External Power	no	no	yes
Complexity	medium	low	high
Cost	high	low	high
Anisotropic Force	no	yes	yes
In-situ Adjustability	no	yes	yes
Form Factor	large	small	small
Force-Duration Thresholding	no	yes	yes
Disconnect sensing	yes	yes	yes

Table 1: Design Comparison

ACKNOWLEDGMENTS

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AN AFFORDABLE MOBILE ROBOTIC MANIPULATOR.

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ABSTRACT

A robotic manipulator has been mounted on a wheeled trolley. This novel approach aims to overcome some of the limitations of a fixed site workstation system, while keeping the cost within reasonable limits. Preliminary user experience with the system is encouraging.

BACKGROUND

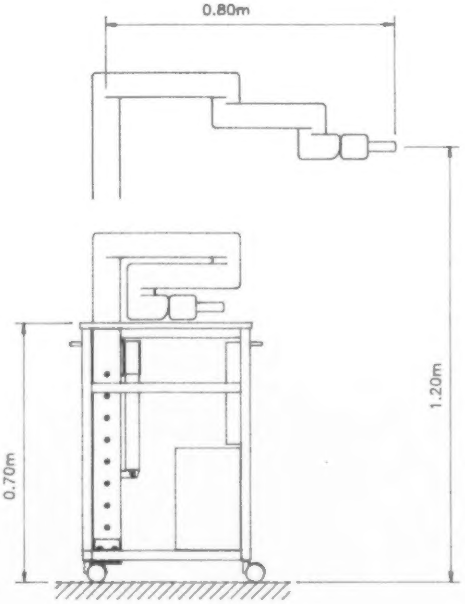
There is obvious potential for using robotic technology to assist those who because of accident, illness or congenital defects do not have full use of their hands or arms. Although the application of robotics to help people with disabilities has been investigated for many year, very few devices have left the research environment and even fewer can claim to have been commercially successful. Several reasons cam be suggested for this failure. One reason may be that few of the devices have been designed as commercial products.

RATIONALE

Our own experience has come from the development of a workstation system [1]. While being able to successfully move and manipulate objects on and around the workstation there were obviously limitations. The main barrier was the physical size of the system. While the size of the workstation was based on a standard office desk, this was still too large for a domestic environment. Additionally it was found that within a home it was limiting for a robotic system to be used in a single room. Rather it should be available for use for different tasks in different rooms.

The idea of a workstation system may be extended in several ways. The aim of mobility has been often achieved either by the use of a mobile robot or by mounting a robotic manipulator on a wheelchair. The approach which we have been following, in the hope of achieving a substantially cheaper product, has been to mount a robotic manipulator on a simple trolley. This may be moved around the home to various local "work sites" by a carer. Alternatively it has been suggested that it might be possible for the trolley to be clipped to a wheelchair so that it might be moved around by a wheelchair user.

DESIGN IMPLEMENTATION



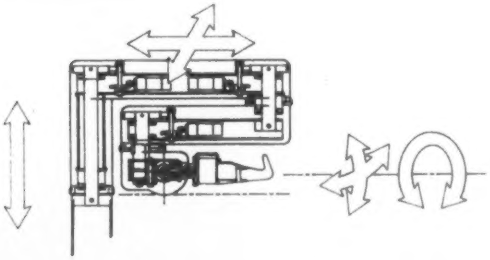
The aim of the design is to produce a stand alone assistive robot which is mobile, yet low cost.

The overall geometrical arrangement was retained from the earlier workstation system. This uses a SCARA geometry for the upper arm with a linear vertical actuator. The manipulator is mounted on a wheeled trolley. 5cm diameter braked castors are adequate for use over carpet, slightly offset from the cabinet at one end for stability when the manipulator is extended.

Vertical actuator

The use of a linear bearing, incorporating a carriage running on a rectangular profiled rail gives low resistance, yet can cope with high off-centre loads. The vertical travel is 0.4m. A constant tension spring balances the weight of the whole manipulator.

Upper arm



The upper arm structure consists of three vertical axes, all to a common design. Since none of the actuators act against gravity low powered motors can be used (4.2W). Thus the manipulator is not powerful enough to harm anyone, yet is able to carry a reasonable load of 2kg. The internal aluminium structure has a cosmetic cover which allows easy access to the mechanical and electrical components.

Wrist pitch/roll assembly

Pitch and roll are implemented by a reverse differential gear system. Currently the end effector is a two motor prosthetic hand, loaned to us by Hugh Steeper Ltd (London, UK).

Electronic control

The motor control boards are mounted within the upper arm structure. The power supply and I^2C serial link from processor to motor control boards run within the manipulator structure. The motor control boards are 5cm x 5cm and use the HP HCTL1100 motor controller. The Pulse Width Modulated output from this is taken to a current limited amplifier to drive the motor.

Aesthetics

Since the manipulator uses an internal structure covered by a cosmetic vacuum moulded cover, it is relatively easy to change the appearance of the upper arm. The trolley is designed so that different colours and finishes can be investigated simply by sliding in new side panels. The manipulator currently has a white and grey trolley with white upper arm and grey vertical post.

User Interface

The user interface uses a scanning menu system on a LCD display. Various parameters of the scanning system (eg number of switches used for input, speed of scanning) may be varied to suit the control abilities of individual users. The LCD unit (19cm x 13cm) is attached to the trolley by a 2m cable, and may be positioned as near to the user as necessary. The manipulator may be controlled directly in real time, though this is a slow and cumbersome method. When the manipulator is "docked" at a local work site, pre-set routines may be used to decrease the control burden on the user. These pre-set routines may be created by the user himself. When replaying a routine the movement may be interrupted to allow for adjustment of the position of the manipulator.

EVALUATION

One of the priorities of the design of the system was that it should be a stand alone product which could be easily transported to, and left at, the home of a user. The system should be usable without an engineer or other professional present.

Initial evaluation results have confirmed that the system meets these requirements. Several improvements have been recommended. In particular it is necessary that the user interface parameters should be variable by the user himself. Continuing trials should show whether such a system can cost effectively perform a useful function for disabled users.

DISCUSSION

The aim of this project has been to build a relatively low cost, mobile manipulator which can perform a useful function in the home of a disabled user.

Mobility

Although systems have been built using advanced autonomous mobile robots, such sophistication is difficult to justify for an assistive robot. A more useful comparison of the current system is with a wheelchair mounted manipulator. The advantages of working in a structured work site must be compared with the advantages of having the manipulator always available to the user.

Ease of use

The system does not require complicated setting up or subsequent intervention by engineers or other professionals.

User interface

While not being sophisticated, the user inteface can be readily used by people with a wide range of abilities. Pre-set routines are widely used, but with the facility for the disabled user to create and modify such routines. Although not implemented yet, it is intended that the user should be able to set up and adjust the parameters of the user interface system.

Low cost

The system has been designed so that it can be produced in small batch quanitities, at relatively low cost. Although production development still needs to be finalised we are hopeful of reaching our target price of under £10000.

Usefulness

Ultimately any assistive device must be judged on whether it can cost effectively perform a useful function for disabled users. Continuing evaluations should provide a realistic answer to this question.

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VIRTUAL PROTOTYPING OF REHABILITATION AIDS

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ABSTRACT

This paper discusses methods of using virtual prototyping to assist with the development and customization of rehabilitation products. The difficulty of designing equipment for individuals with physical disabilities is that each individual presents a unique neuro-physiological picture. This research explores ways in which virtual device design and evaluation can be combined with new techniques in rapid prototyping to create efficient rehabilitation devices.

INTRODUCTION

Due to the considerable diversity of users' physical abilities, there exists a need for designing devices which are user specific. This design cycle is complicated by the complexity of the device and the small market size. There are also numerous biomechanical factors that need to be considered. The techniques of virtual design and rapid prototyping are ideally suited for assessing these factors as well as rapidly designing and manufacturing one-of-a-kind rehabilitation devices.

A method of designing and fabricating rehabilitation devices has been proposed which attempts to separate the user interface design from the supporting features design [5]. The fundamental assumption of this method is that most of these supporting features can be acquired from conventional design techniques, whereas the user interfaces must be customized for each individual. Wheelchair seating and controls, prosthetic arms and legs, as well as the Magpie [2] are instances in which this method has proven to be useful. Consequently we are attempting to develop a representation for design abstraction and associated reconfiguration mechanisms that may be used for the development of other configurable and extensible devices. The development of this representation involves the use of graphical computer models and interface devices to support the development of virtual mechanisms as well as facilitating the analysis of user tasks and user abilities.

BACKGROUND

Assistive devices need not be complex for them to be useful in tasks of daily living. Simple designs are often more reliable, have a lower cost, and are more readily accepted. The Winsford Feeder [4] and the Magpie [2] are examples of widely used rehabilitation devices which have a simple design and are suitable for a wide range of disabilities. However, the major disadvantages of these devices are their inability to be readily adapted, their long manufacturing time and their high cost.

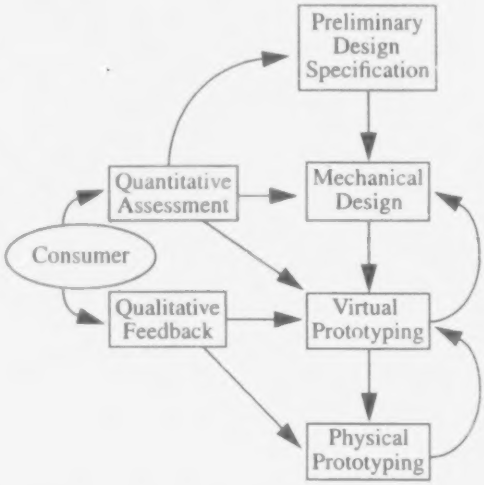

Figure 1: Rapid Prototyping of Rehabilitation Aids Development Cycle

Effective design of rehabilitation devices necessitates the quantitative assessment and feedback of the disabled person's performance as well as a method for quickly designing and prototyping assistive devices based on performance goals. Our complete approach (shown in Figure 1) to design and prototype passive, assistive, mechanical devices involves:

- the quantitative assessment of the form (geometry) and performance (kinematics, dynamics) of human limbs using sophisticated methods from computer vision and biomechanics
- design of the assistive device
- evaluation of the device using simulation and virtual prototyping
- feedback from the consumer and associated

personnel such as the therapist or physician
- actual prototyping of the assistive device
- evaluation of the function and performance of the device
- redesign based on performance

This paper focuses on the simulation and virtual prototyping aspects of the development cycle, which involves assessing the user's capabilities, rapid creation of virtual devices based on kinematic specifications and anthropometric data of an individual user as well as allowing the user to test and qualitatively access the capabilities of a prototype.

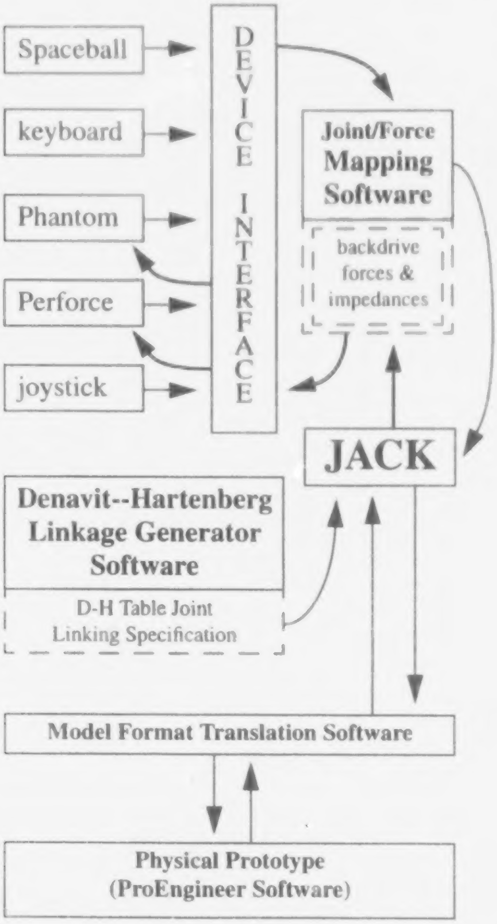
Spaceball
keyboard
Phantom
Perforce
joystick
DEVICE INTERFACE
Joint/Force Mapping Software
backdrive forces & impedances
JACK
Denavit--Hartenberg Linkage Generator Software
D-H Table Joint Linking Specification
Model Format Translation Software
Physical Prototype (ProEngineer Software)

Figure 2: Virtual Prototyping Conceptual Diagram

METHOD

The research into the virtual prototyping aspects of this project is being conducted using a Silicon Graphics workstation with a Spaceball 3D input device. To display graphical objects we are using JACK™, a software application which displays and manipulates articulated geometric figures and includes a human body model which can be customized to a specific set of anthropometric variables. These components allow us to interactively control 3D graphical objects with simultaneous six degrees of freedom. A Spaceball™ 6DOF isometric joystick, which has proven effective in controlling rehabilitation devices in the past [6], allows the designer and user to experiment with controlling the virtual prototype device. The different degrees of freedom of the virtual prototype device can also be controlled with keyboard inputs. Additional input devices are also going to be integrated into the system, including both a PER-Force Handcontroller and a Phantom™ which will allow the system to give haptic feedback to the user.

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0°	0	0	θ_1
2	-90°	0	0	θ_2
3	0°	85.0	-38.5	θ_3
4	-90°	-8.5	84.98	θ_4
5	90°	0	0	θ_5
6	-90°	0	0	θ_6

Figure 3: Denavit-Hartenberg Parameters for the PUMA Robot

The first step involved in the virtual design process (shown in Figure 2) is the definition of the prototype device. The designer accomplishes this by defining the Denavit-Hartenberg parameters [5] of the device they are prototyping. The Denavit-Hartenberg notation is a common kinematic protocol used by designers for defining a device's movements. After the designer has inputted the Denavit-Hartenberg parameters (shown in Figure 3) our software automatically generates a 3-D graphical model of the device (shown in Figure 4) that can be manipulated by the user. This allows the designer to define which external inputs control the movements of the different joints of the device. The model of the device can be altered interactively by the designer, so that she can customize it according to feedback from the user and the evaluation process.

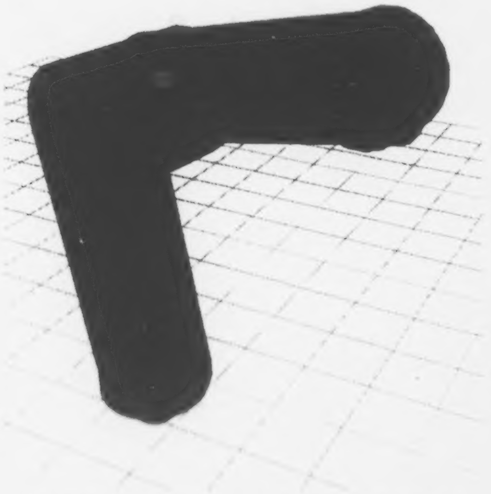

Figure 4: Virtual Model Generate from the Denavit-Hartenberg Parameters of the PUMA Robot

The last component of the virtual design process allows the designer to take the virtual model of the prototype and translate it into a format that can be inputted into a CAD design package (ProEngineer™) to generate the physical prototype [3].

CONCLUSION

This research is part of a larger consumer focused design program that is investigating methods of product design that are adaptable to consumer needs, are cost effective and exploit new methods of agile manufacturing and rapid prototyping. This design program is based on the belief that the best designs for products are consumer initiated and have significant involvement of consumers in their design. Through the development of these new computer-integrated design tools for the quantitative assessment of function and performance of humans we are hoping to facilitate the design of customizable rehabilitation devices.

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A BODY POWERED REHABILITATION ROBOT

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ABSTRACT

This paper describes a wheelchair mounted, gravity balanced, mechanical arm whose end point is controlled and powered by a functional body part of the user, via Bowden cables. Two important design features are adaptability to different user input sites and ability to provide external power augmentation. The salient design features of such a system and the development of a prototype are described.

BACKGROUND

There are currently a handful of rehabilitation robots commercially available. One of these is the Manus [1] manipulator. This robot is an electric motor powered, wheelchair mountable device which allows several modes of user control, such as joint-level and Cartesian end-position. DeVar [2] is a work station robotic system which can be used either in a structured or unstructured environment through voice control. While these rehabilitation robotic systems can be fairly easy to use, they are costly (in the $40,000 range), prone to frequent electro-mechanical failures, and provide only visual feedback to the user. The Helping Hand, Handy 1, and Magpie are three lower-cost rehabilitation robots. The Handy 1 [3] is primarily used as a feeding device through switch control of pre-programmed movements, which limits its functionality. The Helping Hand [4] is a wheelchair mounted, electric motor powered, robotic arm which is controlled by the user at the joint level, via a joystick. The Magpie [5] is a body powered and controlled, mechanical robot. It couples spoon motions (output) to the user's foot motions (input) through Bowden cables. The great advantages of this system are design simplicity, low cost, extended physiological proprioception (EPP), and force reflection. The project proposed in this paper combines the simplicity of the Magpie with the functionality of a higher degree of freedom device.

PROBLEM STATEMENT

The goal of this work is to develop a technologically simple, wheelchair mounted manipulator to allow a person with no or very little arm function to interact with his surroundings. It has been shown that a system which compliments visual feedback with sensory channels is superior to visual feedback alone [6]. The intended population that would benefit from such a device has physical disabilities such as spinal chord injury, multiple sclerosis, and cerebral palsy. The following four features highlight the design objectives.

- Intuitive and easy to use - The inputs of the user should map in an integrated manner to the outputs of the manipulator: a proportional, three dimensional position mapping of the user's input position signal to the position of the arm's gripper is desired. A direct connection between the user interface and arm facilitates a system which is easy to use since proprioception and force reflection are naturally built into the control system.
- Modular - The system will be modular in two senses. First, the arm will accept several different user inputs. These inputs depend upon the available user body motions, which to a large extent, depend upon the user's disability. For example, if the best available user input is from the head, the arm needs to accommodate whatever interface is designed for head input. Alternatively, if the best user input is from his hand, the arm needs to accommodate whatever interface is deigned for hand input. Another way the system needs to be modular is in its ability to accept power assist units. In this way, if the user can not supply sufficient power to the interface to directly cause the arm to move, power amplifier modules will be added to specific joints to assist the user in operating the arm. The issue of desiring minimal user input power naturally leads to the requirement of arm gravity compensation throughout its range of motion.
- Cost - The high cost/usefulness ratio of most rehabilitation robots makes their use very limited. It is the goal of this project to maintain a simple design philosophy so costs can be kept at a minimum.
- Aesthetics - The arm is designed to geometrically and functionally resemble a human arm. The interface unit will be designed as unobtrusive as possible and the cable routing will be neat.

PROTOTYPE DEVELOPMENT

To date, two arm prototypes have been designed and constructed and two interface units have been designed, one for the head and the other for the hand. As a start for constructing a prototype, head input was chosen. A schematic diagram of the main system components, namely the arm (without a gripper) and head interface unit, both attached to a wheelchair, is shown in Figure 1. One of the design objectives was to have an end-point controlled, mechanical linkage which resembles the human arm. To facilitate this objective, a spherical coordinate system $\{\theta^A_1, \theta^A_2, \rho^A_3\}$ was chosen for the arm with an extra degree of freedom (θ^A_4) added to kinematically couple head input to arm motion. A detailed drawing of the arm is shown in Figure 2. A direct mapping exists between the yaw ($\theta^A_1 \rightarrow \theta^I_1$), pitch ($\theta^A_2 \rightarrow \theta^I_2$), and roll ($\theta^A_4 \rightarrow \theta^I_4$) axes of the arm and head interface, while a proportional mapping is present between the linear, horizontal motion of the user's head (corresponding to the θ^I_3 revolute joint of the head interface) and the radial (ρ^A_3) motion of the arm. Radial motion of the arm is achieved through the use of three pulleys. As seen in Figure 2, many links and joints run alongside the main arm beams; the purpose being to constrain the arm to move in its designed coordinate frame, $\{\theta^A_1, \theta^A_2, \rho^A_3, \theta^A_4\}$. Although not shown for the purpose of clarity, Bowden cables connect the arm's coordinate frame to the head interface unit. In order to minimize friction, thereby reducing the power required by the user to operate the system, the GORE-TEX™ RideOn™ Derailleur Cable System is used for Bowden cables. The four bar linkage design of the arm's main beams is to allow gravity compensation (not shown) of the mechanism throughout its full range of vertical motion as discussed in [7]. An additional design feature is the constant vertical orientation of the distal link, thus giving the user drinking capability.

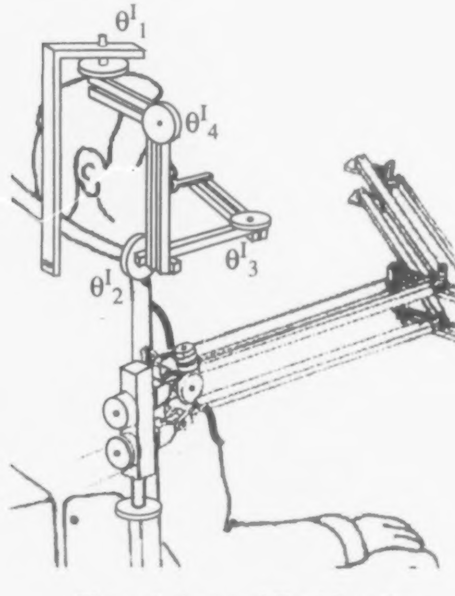

Figure 1: Arm and Head Interface

DISCUSSION

Although the general system layout has been thought-out and addressed through the help of consumer input, several issues still need to be resolved. It is envisioned that, with head input, the user will move the gripper (attached to the arm's end) by a head interface unit which fits in the user's mouth. When the gripper approaches the vicinity of the user's face for tasks such as eating, the user can disengage from the head interface. The user will operate the gripper through movements in the tempo-mandibular joint. The following issues still need to be addressed.

- Gripper - A gripper and its connection to the interface unit needs to be designed and built to allow the user to manipulate items in his environment.
- Safety - Large forces applied to the arm transmit large forces and torques to the human interface and hence, the user's head. A means to avoid this occurrence needs to be devised.
- Donning/Doffing- Since this system will be secured to a wheelchair, adjustability for allowing the user to easily engage/disengage from the system is required.
- Adjustability - To allow recalibration of the system and to allow the robot to fit many users, variables such as link lengths and cable connections need to be adjustable.
- Power assistance - Although the design will try to reduce friction as much as possible, the user may not have sufficient strength to completely body power the arm. To compensate, mechanical power amplifier modules are currently being investigated to determine if they can be designed into the system.
- Locking - The user needs the ability to lock the arm in position when moving heavy loads or needs to use his input site for a purpose other than operating the arm.

SUMMARY

This paper discussed how a mechanical arm could be used by a person with a physical disability to allow them to more fully interact with their surroundings. The advantages of the proposed system, namely, low

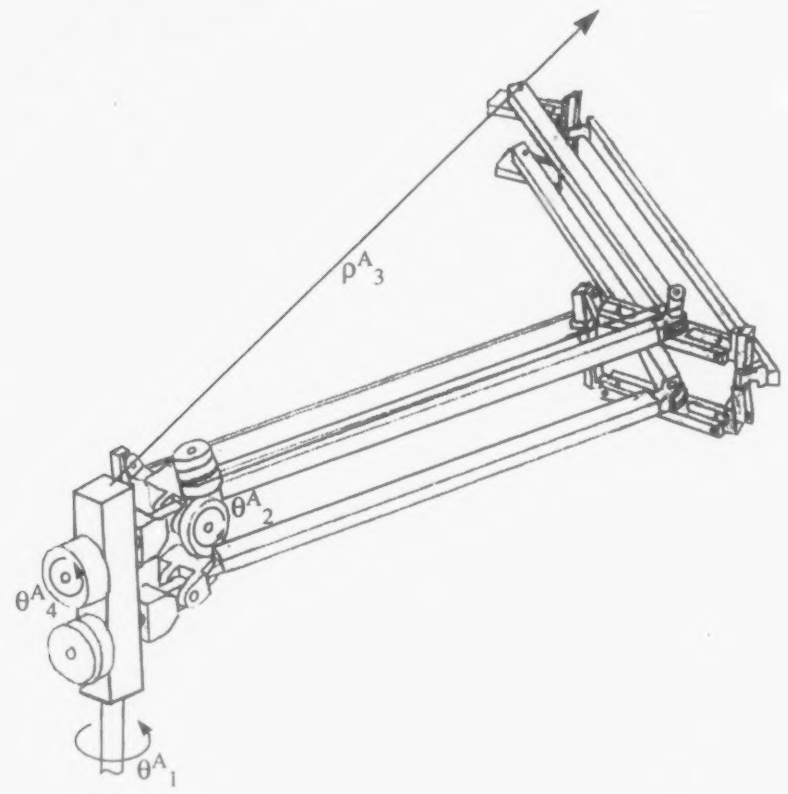

Figure 2: Mechanical design of arm and its coordinate system

cost and ease of use were highlighted. Presently, prototype designs for the arm and multiple input units are under development. During development, the system will undergo evaluation on such tasks as eating and page turning. Evaluation criteria will include items such as, completion time, required effort, fatigue, and subjective comments.

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SIG-14
Job Accommodation

$80,000 WORKSTATION WITH NO-COST ACCESSIBILITY

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Wichita, Kansas

ABSTRACT

Job accommodations for persons with disabilities are generally made by modifying a workstation that has been previously in use by another person. A totally different approach was used in the development of the workstation portrayed in this case study. A new process and machine was required to drill the mounting holes in aircraft window frames. The new machine and workstation were designed, fabricated, and set up to accommodate a person who uses a wheelchair. Since accommodations for the operator were considered from the start of the design process it can be shown that the "accommodation" in this case was made at no additional cost. Features of the workstation and its operation are discussed.

BACKGROUND

The windows located in the passenger compartment of Boeing airliners have a frame that is an aluminum forging. Installation in the fuselage structure requires that 22 mounting holes be pre-drilled in the frame. Drilling of these mounting holes was accomplished by a worker using a hand-held drill, drilling one hole at a time. The drilling process required 20 to 25 minutes per frame. A subcontractor was offered the drilling operation if time and money could be saved. The subcontractor has a history of employing persons with disabilities whenever possible. Rehabilitation engineers who had manufacturing experience were employed to design a drilling machine that would hold the frame firmly while the 22 holes were being drilled in a gang drilling operation. The machine was designed, fabricated, and put in operation under scrutiny of Boeing manufacturing personnel. The philosophy applied in the design was crucial to the success of the project. Locations for the holes, and the diameters were set with extremely tight tolerances (typical of aircraft manufacturing). It was difficult to design the machine to simply do the drilling operation, but features which accommodate a person in a wheelchair did not complicate the process of design and fabrication.

OBJECTIVE

The objective was to design a machine that would hold the window frame firmly while 22 mounting holes were being drilled automatically without moving the frame in the process. Of utmost importance was that the finished product had to meet the strict aircraft standards and tolerances.. Secondarily, but crucial, in the design process, the designers were to make the machine part of an overall workstation that could be operated by a person who uses a wheelchair. In particular, the goal was to make the workstation accessible and operable by a person who has severe disabilities.

APPROACH

Handling of the parts was a major consideration. It was determined that parts prior to drilling would be supplied to the machine operator in stacks within reach of a seated position by persons who are ambulatory. After drilling, the parts would be stacked by the machine operator and moved on by others in the shop.

Placement of undrilled parts was to be facilitated by guides with an assist from gravity. The term "funnel effect" has been used to describe the use of guides assisted by gravity. Utilization of the funnel effect is most helpful for persons who have "unsure" hands.

Twenty of the 22 holes are drilled with the drills positioned in one plane. The drill motors drilling the 20 holes were mounted on a single plate. The plate was then mounted on support structure. There are 10 air driven motors, each having a gear head which holds two drill bits. Thus, each of these drill motors drills two holes at a time. The mounting plate is positioned 15 degrees from the vertical which provides for components of gravity to assist vertically and horizontally in the placement of undrilled parts in the clamping fixture. Pneumatic powered clamps are activated by a push button close to the operator. In fact, the utilization of a programmable controller provides the capability of the machine to cycle through its entire drilling operation by pushing the one button. The two remaining holes are drilled perpendicular to the plane of the mounting plate and are positioned at the rear of the plate. The drills pass through the mounting plate to reach the part.

Figure 1 shows the drilling machine and the positions of the drill motors that are positioned parallel to the mounting plate.

Figure 2 shows the operator in position to do the parts handling and monitoring of the machine's operation.

Figure 3 shows a cross section of the window frame and directions of the drills.

RESULTS

The drilling operation utilizing the new machine requires one minute ten seconds. A minimum of 19 minutes is saved for each window frame that is drilled. The design was carried out as a research project. However, accounting for engineering and fabrication time the new machine would have a cost of $80,000. The costs saved due to reduction in time will pay for the machine in less than one year. Two different persons are the main operators. One has cerebral palsy and uses a wheelchair for mobility. The other is legally blind and can use only one hand to handle parts. Both of these operators are capable of producing quality parts at the required production rate. Quality of the finished part is of utmost importance since the cost of a single part being rejected is approximately $160.

DISCUSSION

It is important to realize that an entirely new machine and workstation were required to accomplish the desired task. The employer was willing, if not eager, to employ a person who has severe disabilities. Combining these two goals in the design and fabrication process resulted in little or no cost being realized because the workstation would be accessible. In retrospect, the set up of the new workstation, and its operation, is better for all persons whether they have disabilities or not.

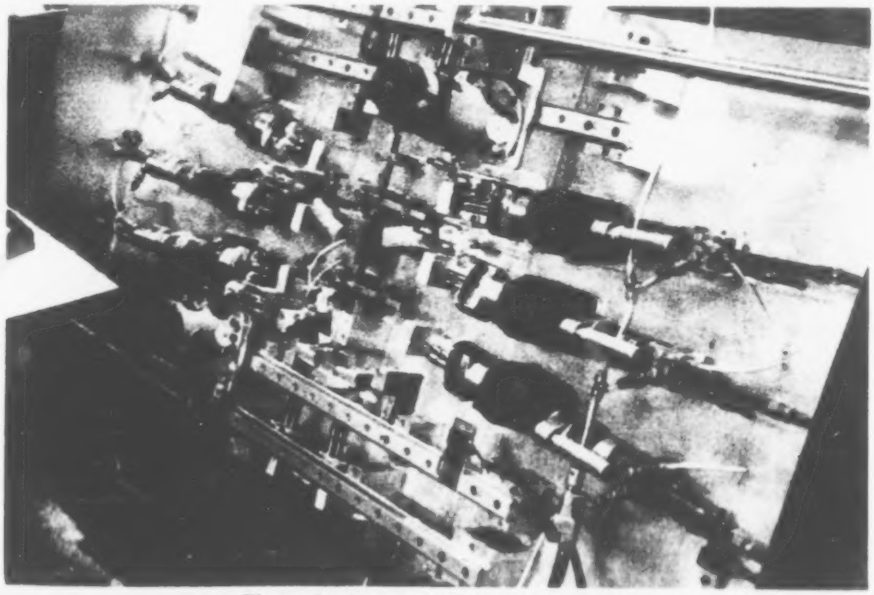

Figure 1. Mounting Plate and Drill Motors

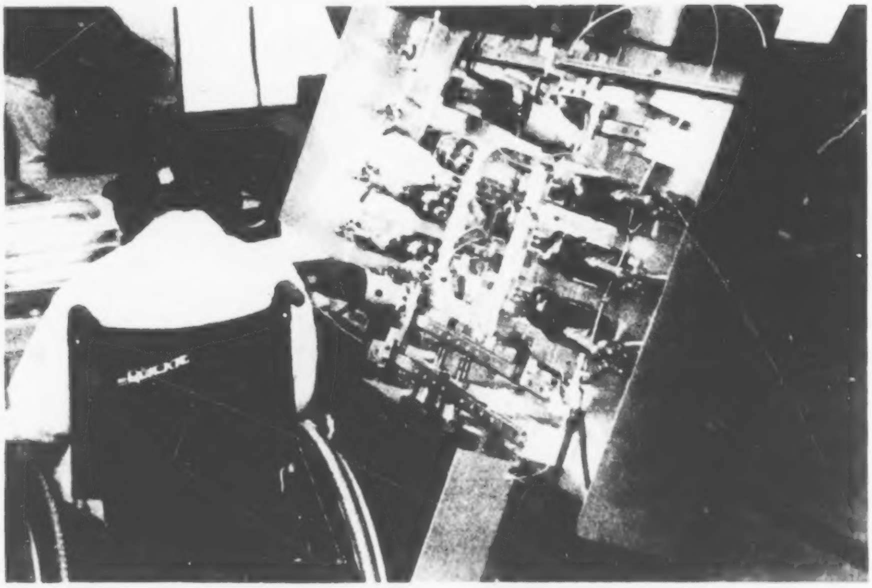

Figure 2. Operator at Machine

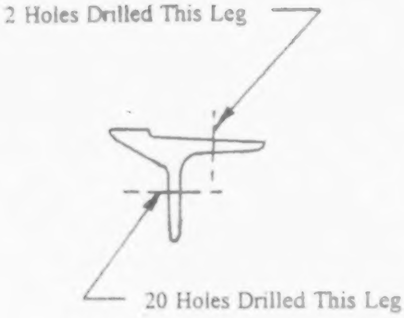

Figure 3. Cross Section of Frame

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A SPEECH RECOGNITION SYSTEM FOR OPERATION OF A VISUAL INSPECTION WORKSTATION

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ABSTRACT

A speech recognition algorithm utilizing the Hidden Markov Model has been implemented for use as voice control of a visual inspection workstation. This system was implemented as a speaker independent, isolated word, limited vocabulary system and trained for a 50 word vocabulary consisting of command words for the workstation. It was tested using 18 speakers, eight male and eight female, and found to have a recognition accuracy of 94.5% over all words and all speakers. The model was extended to recognize the speech of a person with a mild verbal impairment due to cerebral palsy achieving a recognition accuracy of 94% over all words. This system will be tested further with other individuals with verbal impairments and made to operate under Microsoft Windows to control a visual inspection workstation.

BACKGROUND

The use of the Hidden Markov Model (HMM) for speech recognition was first proposed by Baker [1]. It has since become the predominant approach to speech recognition, superseding the Dynamic Time Warping (DTW) technique. It has been found that the overall recognition accuracy and performance of the HMM is comparable to that obtained using a DTW algorithm with much less computation and storage requirements.

With the HMM technique, the speech recognition process is generated by two interrelated mechanisms, a Markov chain having a finite number of states and a set of random functions, one of which is associated with each state. At discrete instants of time, the process is assumed to be in some state and an observation is generated by the random function corresponding to the current state. Each state is capable of generating a finite number of possible outputs. The Markov chain then changes states according to its transition probability matrix.

It is quite natural to think of the speech signal as being generated by such a process. We can imagine the vocal tract as being in one of a finite number of articulatory configurations or states. In each state a short signal is produced that has one of a finite number of prototypical spectra depending, of course, on the state. Thus, the power spectra of short intervals of the speech signal are determined solely by the current state of the model while the variation of the specral composition of the signal with time is governed predominately by the probabilistic state transition law of the Markov chain [2].

RESEARCH QUESTIONS

This research sought to answer the following questions:

1. Can a user independent, isolated utterance, small vocabulary speech recognition system be developed to assist an individual with hand motor impairment operate a visual inspection workstation?
2. Can this system be extended to assist an individual with verbal impairment?

METHOD

In training the HMM system, nine normative speakers were used with each speaker saying the same word, in isolation, 5 times. Some effort was made in recording these words to make sure that the sing-song tendency of some speakers saying the same word 5 times in a row is minimized. The speech wave files were edited to remove the silence at the beginning of each word. All speech files were sampled at 22050 Hz, with 16-bits per sample. The sound files were recorded using the mono input of a Pro-Audio Spectrum-16 sound card. The subject was isolated in a sound proof, sound booth.

All recorded speech files were down sampled to 11025 Hz. For calculating the Linear Predictive Coding (LPC) parameters and cepstral coefficients, each speech waveform was partitioned into frames of 30 ms each with an overlap between adjacent frames of 15 ms. A Hamming window was used on each frame. The order of the LPC parameters was 10 and the dimension of the cepstral coefficients was 12. A 256 entry codebook for all the cepstral vectors of all words in the vocabulary was created. A model for each word in the vocabulary set was created (i.e. the A and B matrices). Left to right model was used with 5 states. The Buam-Welch algorithm [3] was used to find the transition matrix A and the output probability matrix B for each word. The block diagram shown in Figure 1 illustrate the process of getting the cepstral coefficients from the speech signal.

The digitized speech signal is processed by a first order digital preemphasis filter in order to spectrally flatten the signal. Sections of consecutive speech samples, corresponding to 30 ms of the speech signal, are used as a single frame; consecutive frames were spaced 15 ms apart with 15 ms frame overlap. Each frame was multiplied by a Hamming window w(n) so as to minimize the adverse effect of extracting a 30 ms section out of the running speech signal. Each windowed set of speech samples is autocorrelated to give a set of eleven coefficients. For each frame, a vector of ten LPC coefficients is computed from the autocorrelation vector. An LPC derived cepstral vector is then computed up to the 12^{th} component for each frame. The 12-coefficient cepstral vectors are then weighted by a cepstral window. From all cepstral coefficients of the speech signals, a codebook was created. Vector quantization (VQ) is then used to map each observation vector into a discrete codebook index using a simple nearest neighbor computation.

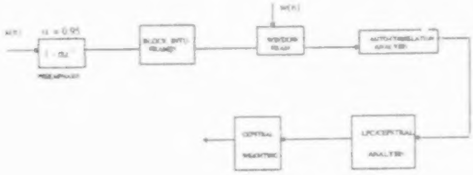

Figure 1. Block diagram of the preprocessing of the HMM system

A distinct HMM was designed for each of the 50 words in the vocabulary. A left to right model with 5 states was used for each word. It is assumed the model always starts in state 1 and ends in state 5. Initial estimates of the transition probability matrix A, and the output probability matrix B were used to get a good final values for A and B for each word, through the iterative Baum-Welch algorithm [3].

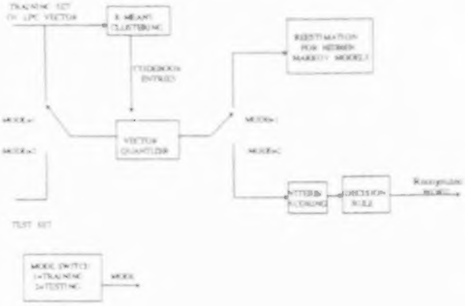

Figure 2. Block diagram of overall HMM system

In the recognition phase, the speech signal is converted into a set of cepstral vectors, from which an observation sequence is obtained using the codebook. Then, the observation sequence is matched successively against each word HMM of the vocabulary using a Viterbi scoring algorithm [4]. Figure 2 illustrates the HMM recognition system.

RESULTS

The basic HMM system was tested using 18 normative speakers (nine males, and nine females) with only two of the speakers used also in training the HMM system. Each speaker uttered every word in the 50 word vocabulary twice. Speech signals were sampled in a noise free environment using a sound card that sampled at 22050 Hz, with 16-bits per sample. All speech wave files were edited to remove the silence before each word. Before calculating the LPC and cepstral vectors of the recorded speech, all files were down sampled to 11025 Hz.

The overall performance of the HMM system on clean speech was 94.5% accuracy. The recognizer system was tested by gender of its speaker to see if there was any difference in the accuracy of the system and also tested by speaker to determine if the system was speaker independent or not. Two people were also in the training group and provided additional speech samples for testing. The HMM system was also tested by word to see if some words in the vocabulary set were recognized by the system better than other words in the set.

First, the HMM system was tested by gender of the speaker across all words. With the female group of speakers the system achieved a recognition accuracy of 95% while when tested on the male group of speakers it achieved 93.9% accuracy. As it can be seen that the female group did slightly better than the male group. But since the difference is small it can be conclude the system was not gender biased.

The HMM system was also tested by speaker across all words spoken by the individual speaker to see if there is any appreciable difference in the accuracy. Some speakers were recognized better by the system than others. The highest speaker accuracy was 97.0%. The lowest speaker accuracy was 87.0%. It was noticed that the speaker with 87.0% accuracy exhibited perceptible breath noise when talking. It was also noticed that the two speakers that were also used in training the system did not do any better or any worse than the other speakers in the testing speakers group (i.e. some speakers did better than these two, others did the same, and others did worse). This means that the system was speaker independent.

The HMM system was also tested by word across all speakers (i.e. same word uttered by all speakers) to see if some words more easily recognized than others. It turned out that some words were recognized very well by the system, while others were recognized with a

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little less accuracy. The highest accuracy associated with a word was 100.0 % (as an example of this is the word "contrast"). The lowest accuracy associated by a word was 83.3% (as an example of this is the word "help"). The HMM system was more sensitive to some words than others. It was also noticed that words with fricative sounds such as "f", and "s" sound were recognized with less accuracy than the other words.

DISCUSSION

The Hidden Markov Model (HMM) was first implement in a DOS environment. The DOS implementation provided a user independent, isolated utterance, small vocabulary, speech recognition system. The Visual Inspection Workstation for which this speech recognition system is being developed is required to run in Microsoft Windows, therefore, the DOS implementation of the Hidden Markov Model was ported to run under Microsoft Windows. The Microsoft Windows implementation added several additional features and offered several advantages that were not present in the DOS implementation.

The first advantage is that Windows provides a software layer between the application and the sound card. Calls are not made directly to the sound card, but rather to the MCI Routines which then communicate with the sound card. This insulates the sound card from the application and allows any Windows compatible sound card to be used. Another advantage is that Windows provides a user friendly interface which can easily be extended to assist persons with disabilities. This extended user interface allows a person with a hand motor disability to control the visual inspection workstation with voice commands. The word boundary and detection routine is an important part of this extended user interface. This routine automatically determines the beginning and ending of each word. Voiced speech is detected by using an energy function, while unvoiced speech is detected by computing the zero-crossing of the word.

The hardware required to run the speech recognition system is a typically configured personal computer that includes a sound card and a microphone. The sound card should be able to sample at 11 kHz with a sample size of 16 bits. The only hardware item that is not included with a typically configured PC is a video captured board. The video capture board is used by the video portion of the visual inspection workstation but is not needed for the speech recognition part.

In addition to this normative code book and model, a second code book has been generated for a speaker dependent model for an individual considered to have mild verbal impairment from cerebral palsy. This code book was generated using eight repetitions of each of the 50 words and tested using two repetitions of each word. This model achieved a recognition accuracy of 94%.

It is unclear, at this time, if a codebook will be required for each individual or one codebook for each disability group. To determine this, data will be collected from persons from several disability groups where the disability is likely to cause verbal impairment and also from multiple people from one disability group with varying degrees of impairment. A different codebook for each disability group will first be generated and the model trained for this codebook. This model will then be tested for recognition accuracy within the group. If the recognition accuracy is comparable to that achieved with the normative data, the individual model will not be developed. If, on the other hand, adequate accuracy in not achieved, individual models for each member of the disability group will be developed and tested.

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JOB ACCOMMODATION FOR REPETITIVE STRAIN INJURY ON THE AUTOMOBILE ASSEMBLY LINE

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Abstract

As part of a project supported by a contract from Saturn Corporation, an assembly line worker with lateral epicondylitis related to job tasks has been the focus of an accommodation project. Observations strongly suggested that her injury was caused in large part by use of a six-pound electric bolt driver for bolting doors to car frames. The supination and wrist flexion loads of the original job have been eliminated and reduced, respectively, by means of a "three-axis-tool-holder". This mechanical adaptation supports one end of the tool on the door-mounting fixture while allowing the operating end to move as it needs to in order to access all four bolts. Early evaluation results indicate work rates comparable to unaided tool use and a high level of worker enthusiasm following initial skepticism.

Background

In June of 1994, Saturn Corporation, in Spring Hill Tennessee, awarded a contract to the Biomedical Engineering Department (BME) and the Rehabilitation Engineering Program (UTREP) of the University of Tennessee, Memphis. The purpose of the eighteen-month project was to establish what could be done to permit assembly line workers with intractable repetitive strain injuries (rsi) to return to their jobs — by applying the mix of knowledge and skills available from the two funded programs. The UT Memphis campus is known as the Health Science Center and is home to the Colleges of Medicine, Allied Health and Graduate Health Sciences. The project research team combines the clinical skills and knowledge of anatomy and physiology one would expect to find on such a campus with experience in biomedical product design. The project has been collaborative, making use of in-house knowledge at Saturn in industrial health, workplace ergonomics, manufacturing engineering and tool design.

At Saturn, as at virtually all manufacturing firms whose work force is engaged in manual and power-assisted assembly, rsi is a cause of concern. Seemingly benign loads and postures, repeated many times — even with carefully-planned rotations and rest periods — can cause or aggravate inflammatory conditions in muscle, tendons and nerves which may become chronic and disabling for some workers. It has been estimated that 48% of recordable industrial ill health is attributable to rsi, and that the annual cost of rsi-related medical bills and lost work time is $27 billion [1]. While Saturn has taken a proactive and progressive approach to reducing the occurrence of such injuries. there is currently a group of workers who are unable to return to their original jobs because of the risk of aggravating their rsi's. The carefully cultivated autonomy of factory floor teams at Saturn and the family-like loyalty their members feel all mitigate in favor of honoring the desire of injured workers to return to their original teams. This fundamental goal set up the engineering challenge the project has attempted to meet.

Problem and Process

In the first phase of the project, the ergonomic and medical staffs at Saturn reviewed the records of their restricted workers to identify four candidates for involvement. Criteria for inclusion included a clear-cut rsi diagnosis, a willingness to cooperate and contribute ideas, an absence of complicating factors and history, and an injury to the wrist, elbow, shoulder or neck. Four potential participants were identified, one with an injury at each of those sites. The research team's task, under the terms of the contract, has been to develop accommodations for these workers which permit them to return to their original teams and perform the full rotation of tasks at acceptable speed and minimal risk of reinjury. Also, any accommodation installed on the assembly line must not impede uninjured workers, i.e. must be found attractive for general use or stay out of the way of workers who do not need to use it.

The remainder of this paper documents the team's work with project participant S whose diagnosis is right lateral epicondylitis, known more commonly as "tennis elbow". The Doors Team to which she is expected to return is responsible for bolting the doors to the automobile "space frame" (the rigid structure which supports the body panels and drive train).

The UT team undertook a sequence of four major tasks:

1- Identify the target assembly operation(s), i.e. those most likely to be responsible for the worker's rsi (diagnosis confirmed by UT physicians and therapists consulting to the UT research team). This phase required application of both clinical wisdom and knowledge of the musculoskeletal anatomy and mechanics of the involved body structures. Its outcome offers only a *probability* of correct identification since the clinical and research literature of rsi offers few guidelines which relate probability of injury to anthropometric variables, load, posture, task repetition rate, work-rest duty cycle, and the presence of other work-related and off-work stressors. Observational data was collected by means of detailed video taping on the assembly line and by capture of postures for statics modeling by using the Mannequin™ anthropometric program (from Humancad®).

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2- Understand in detail the anatomical structures which are loaded by the target operation — and how job-related external forces and torques map to internal stress those structures. Statics modeling was used to estimate the injurious loads at the lateral epicondyle. During the process of loading a bolt into the driver end of the tool, S and other workers typically support its six pound weight, cantilevered from the right hand, supported *only* by that hand, with the forearm pronated and neutral wrist extension. This requires a 39lb-in supination moment and a 21lb-in extension moment. The muscles responsible for the forces which produce these torques have their origin at the lateral epicondyle at the elbow end of the humerus. The mechanical disadvantage of these muscles, in particular relative to the 6.5in moment arm to the tool center of gravity, results in a muscular force at the lateral epicondyle of over 400lb. It was this load which the UT team sought to reduce by an order of magnitude. In addition, the dynamic "kick" of the tool when the bolt is "driven home" with a torque of 310lb-in is transmitted to ground via the wrist extensors and the bones of the upper extremity. The accommodations were meant to provide an alternative transmission path, i.e. to avoid requiring the limb to sustain the kick.

3- Design and prototyping of alternative conceptual designs for consideration by Saturn personnel. Virtually all staff members with an interest in job performance and health on the Doors team were involved in this process, in particular S, her co-workers, and the Saturn industrial physician, ergonomics experts, manufacturing engineers and tool designers. During this lengthy and iterative stage, the UT team represented ideas as drawings and physical mockups. The Human Function Lab at UTREP was set up with a '95 Saturn space frame to assist the designers, and S was brought there to simulate use of mocked up tools and to provide design input.

4- Installation and evaluation of line-ready hardware. Prototypes considered ready for trial use were typically demonstrated off-line first to members of the Doors team, in particular their ergonomics representative. More complex solutions were set up and simulated first at Saturn's Workplace Development Center, the development laboratory where assembly line changes are prototyped and evaluated. Each of the three designs described below was subjected to a period of actual use on the assembly line by several workers. This first evaluation period served either to reject a design for reasons inherent in the design, return it to the design team for further development to remedy less important inadequacies, or accept it as ready for hand-off to Saturn tooling designers for final modifications and replication for installation on the line and long-term evaluation.

Design Outcomes

Three designs have been prototyped and evaluated by members of the Doors team on the Saturn assembly line. The first two were found flawed in fundamental ways and abandoned for this application.

1- Belt-worn tool rest. This was by far the most economical of the three accommodations, consisting of a simple trough mounted on a standard commercial tool belt. It was intended to support some or all of the weight of the tool, thereby eliminating the need for the worker to apply a supination moment when loading bolts and reducing required wrist extension forces. It was also meant to transmit the tool kick to ground via the worker's pelvis and legs rather than upper extremities. Various versions were built incorporating some differences in materials and dimensions. All permitted the tool rest to swivel about an axis normal to the belt surface to make it possible to access all four bolts while the trigger end of the tool is continuously supported on the tool rest.

The outcome of trial use by several workers was a perception that donning and doffing time was not worth the functional gain. More important was the determination that workers found it necessary to bend in uncomfortable ways to permit the driver end of the tool to reach all bolts while taking advantage of the tool rest. Finally, the belt-worn tool rest introduced a potential hazard by snagging on parts of the door-mount fixture and other equipment.

2- Flexible drive shaft and remote power unit. The essential concept in this design is that the worker needn't carry the weight of most of the tool, i.e. the motor and gear train, if it is mounted on the door-mount fixture and drives the bolts via a sheathed flexible shaft (like a heavy-duty speedometer cable). Ideally, the worker would only need to support the working end of the shaft whose flexibility would allow easy access to all bolts. Further, the reaction force for tool kick would be provided by the door-mount fixture via the shaft, thereby bypassing the worker's limbs altogether.

For this application, prototype implementation of this concept fell well short of the design's conceptual advantages. The standard Atlas-Copco tool was used as the fixture-mounted power unit, driving a flexible shaft through an coupling. The 5/8in gauge of the commercial flexible shaft (S.S. White Company) required for the necessary torque results in an excessively stiff shaft which is unacceptably difficult to position at all four bolt heads. The relatively short distance between the tool mount location and the four bolts further aggravated the stiffness problem by allowing a flexible shaft only one foot long. This required a tool mount which permitted the tool to pivot about two axes and translate linearly. During trial use, it was recognized that this 3-axis mount might itself be an effective accommodation.

3- Three-axis tool holder (3ath). In its delivered (fourth prototype) form, the 3ath consists of a clamp for the standard Atlas-Copco tool mounted on a custom-fabricated universal joint to permit angular

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travel vertically and laterally relative to the car. This assembly is mounted on a carriage which rides on a splined shaft via a recirculating-ball bushing. The functional outcome is that the worker need only be concerned with the driver end of the tool, to which the trigger has been transferred by means of a simple push-rod linkage. Since the tool clamp supports the tool at a site two inches in from one end, part of the tool's weight counterbalances the rest. The result is that the downward load in the worker's hand is less than half the tool weight, i.e. 2lb 12oz. The entire unit is mounted on a base plate which is secured to the door-mount fixture via two quick-release clamps so that in the event of failure it can be swapped with a replacement without stopping the assembly line. The only modification to the tool itself is the use of right-angle power cord to avoid snagging on parts of the door-mount fixture. All components except commercial bearings and the splined shaft are machined from Aluminum and the device is light enough to be easily hand carried when being transported off-line.

Evaluation

At this writing, the delivered version of the 3ath is about to be used on the line for a sequence of several shifts at a time. The Saturn manufacturing engineers and tool designers are making close observations of the accommodation and its use prior to making a final decision to replicate it for the three other door-bolting stations. Their intent is to modify details of the delivered design in any way necessary to make it consistent with Saturn standards for tooling, in particular to insure sufficient reliability under assembly line conditions and speed of swapping with a replacement. An unanticipated observation from more than one member of the Saturn staff is that the 3ath will make it much more difficult to inadvertently cross-thread a bolt by driving it at an angle. The most direct evaluation of it's success will occur, of course, if S returns to the Doors team and determines whether she can rotate through the modified bolting operation with her team mates according to a regular schedule without sustaining an recurrence of her epicondylitis symptoms.

In it's first on-line evaluation, which lasted over two hours, over ten workers used the 3ath to assemble left front doors on production automobiles. Worker speed with the unfamiliar accommodation was at all times adequate to maintain line speed. No mechanical difficulties were encountered and dis/mounting was accomplished during ten-minute break periods. While new users' initial attitudes ranged from enthusiasm to skepticism, expressions of approval were virtually unanimous following use. Five workers were timed to record the total time required to drive all the bolts for each door. Two were on average faster than their unaided rear-door counterpart, and three were slower. All were within the range of inter-worker and intra-worker variability typically observed with the unmodified tool.

In addition to delivery of a mechanically successful job accommodation which appeals to S's co-workers, this project has had generalizable outcomes at a different level. Lessons have been learned about interactions between an academic r&d team and the workers for whom technology is being developed:

1- Timeliness is next to godliness when it comes to adhering to schedules for demonstration and delivery of prototypes. Expectations of assembly line workers, based presumably on past experience, are such that many are likely to interpret a delay of weeks in meeting a deadline as evidence that the academic team is not really committed to making a difference on the factory floor. Although any communication helps, working hardware — on site — speaks louder that any number of e-mail messages and phone calls.

2- Credibility capital can also be wasted by delivery of prototypes which fail to perform well. While there is an understanding on the part of people on the line that new hardware needs to be debugged, there is detectable damage to the design team's reputation each time a device iteration shows up flawed by failure to foresee an "obvious" problem.

3- The value of learning from the intended users of a new device is an often-stated lesson for new design engineers. Nevertheless, it cannot be overstated and turns out to be true in some unexpected ways. The UT team found that face-to-face conversation with workers had value not only in providing answers to questions important to the design process, but also for detecting dimensions of the task which simply hadn't occurred to them. For example, the workers' desire to have all components of the position and orientation of a tool under their control in order to finesse anomalous occurrences without falling behind line speed was an unexpected finding which helped to explain their initial skepticism about the 3ath.

4- Another value of frequent face-to-face communication between the academic design team and the workers is purely human. *Being there*, frequently and regularly, has the palpable effect of making one part of their family. This familiarity earns a level of cooperation with and appreciation of the project without which it is unlikely to succeed.

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CUSTOMIZING ADAPTATIONS FOR JOB DEVELOPMENT: A CASE STUDY

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ABSTRACT

This case study provides an example of how the consideration of assistive technology enhances the job development process. The customized job adaptations described in this study were developed by a transdisciplinary team. This "Tech Team" was led by a 59-year old woman with cerebral palsy, who was interested in leaving sheltered employment to find her first competitive job. She decided to pursue employment based on her data entry skills. The team designed and constructed an adaptive device to increase her accuracy and speed. Using this adaptation to demonstrate her skills, she applied for employment as a data entry clerk. After she was hired, subsequent modifications to further customize the device were necessary to meet the specific demands of her job. Success on the job has led to many positive changes in her life including increased wages, interaction with co-workers without disabilities and an ever-widening circle of friends.

BACKGROUND

Sonia was born with severe physical disabilities as a result of cerebral palsy. She requires support to do almost all daily tasks, e.g., eating, dressing and making phone calls. Sonia has had a number of surgeries throughout her life in order to alleviate tendon and ligament contractures and increase her range of motion. Her only volitional and consistent muscle control is located in her neck muscles. Sonia operates her "tilt-in-space" power wheelchair controls with her chin and uses a head wand to access her keyboard.

Sonia's family had few expectations for their daughter, based on her intensive medical needs. After living at home for a brief time, Sonia spent the next 57 years living in convalescent and group homes. In 1983, she entered a sheltered workshop with the goal of attaining employment. Sonia spent the next 10 years performing data entry and word processing duties in the workshop. In 1993, Sonia volunteered to participate in a collaborative project between SDSU Interwork Institute and United Cerebral Palsy-San Diego called "Project Real Move". The mission of the project was to support people in the workshop in finding competitive employment in the community. Before a job search was initiated, Sonia met with project staff and friends from her church to talk about her dreams for the future. After experiencing several of these person centered planning meetings, Sonia was ready to explore the use of customized assistive technology for marketing herself to potential employers.

A referral was made to Interwork Institute's Applications of Technology project. The first step when any referral is submitted for consideration is to pinpoint the targeted activity and ensure that the outcome results in increased participation in the community. Sonia's idea met these criteria so the next step was to complete an assessment of her skills and needs. Typically, a videotape is made of the individual, preferably in the environment where the adaptation will be used. The initial video in this case was filmed at the workshop where Sonia continued to perform her data entry responsibilities.

OBJECTIVE

The objective for the first adaptation was to enable Sonia to enter data onto her computer more accurately and quickly. Sonia's strength and coordination were in her head and neck muscle control. She had learned to enter computer data using a head wand but said that her greatest challenge was keeping her place on the data sheet as her attention shifted from the keyboard to the computer screen and back to the data sheet. A switch-operated "highlighter" was made to meet this need, which helped Sonia to increase her speed immediately. After acquiring a job at Road Runner Sports, Inc., additional modifications were made to this device plus the following adaptations were constructed: 1) a device to hold and process catalog request postcards; 2) a drink holder/dispenser; and 3) two wheelchair posts to stabilize her arm movements.

METHOD

A Tech Team was formed to brainstorm solutions to meet Sonia's identified needs. Her original team involved her supervisor at the workshop, SDSU mechanical and electrical engineering students and "Real Move" project staff. The composition of tech teams may change as the needs of the individual change. In Sonia's case, one team designed the original device and another group of people formed a second team to make the subsequent modifications. Teams follow a design process which includes interviewing and assessing the individual who requested the adaptation, researching assistive technology sources to locate commercially available items, designing a prototype, field testing the model and finally, building the adaptation (Sax & Kozole, 1994).

The development of Sonia's device began with the team modifying a free-standing clipboard to hold Sonia's data sheet. At the top of the clipboard, a 9 volt DC motor was used to advance a horizontally mounted drive shaft. The drive shaft was connected to a second shaft, located at the lower portion of the clipboard, by two vertical belts holding a single, horizontally mounted 2" x 10" piece of clear Plexiglas™. This Plexiglas™ strip "highlights" the targeted line on her data sheet. The control logic allows Sonia to index the "highlighter" one line at a time by pressing a large switch with her head wand. When the highlighter reaches the last line of information, a trigger switch returns the highlighter to the top of the page, so that a new data sheet may be manually inserted. The highlighter guide was calibrated to accommodate various predetermined line settings. By selecting one of three settings, Sonia was able to customize the device to meet her changing data entry needs. The clipboard highlighter is designed to be free-standing, with an integrated keyboard and base that can be adjusted for different seating angles, thus maintaining the optimum placement. Sonia became adept at using the device and quickly increased her productivity and accuracy. Project staff involved in the job development search designed a "portfolio" to showcase Sonia and her new device to potential employers. The portfolio included a short video and pictures of Sonia using the device as well as a resume and samples of work.

After seeing Sonia's portfolio, the manager of Road Runner Sports, Inc. offered her a job entering information that was written on 3"x5" catalog request postcards into a database. A new device was required for Sonia to accomplish this job. Sonia's Tech Team reconvened with a new member, a representative from Road Runner who was familiar with the data entry requirements of the postcards. The new device was an oversized Plexiglas™ copyholder, supported at an 45 degree angle with adjustable brackets, and fitted with three 3"x 3"x5" bins placed horizontally across the top. A stack of postcards ready for data entry were placed in the middle bin, against a spring-loaded surface. After entering the data, Sonia used her head wand to move the card to the bin on the right side. If she encountered a card that she could not read, she moved it to the left bin to be checked by a co-worker. Shortly after Sonia's starting date, the company temporarily ceased the postcard campaign and it appeared that Sonia's job was in jeopardy. With further discussion between Road Runner and Interwork staff, they realized that there seemed to be an endless supply of address changes to correct. The tech team convened once again to modify Sonia's original "highlighter" device according to the job requirements. The new, improved version accommodated 15" wide computer paper which was inserted horizontally. This device became the cornerstone upon which all of her job duties were assigned. Sonia thought that she might be able to improve her performance if the printout was enlarged. One of her co-workers volunteered to do this on an ongoing basis.

As Sonia became more comfortable with her new surroundings, she began to think of other adaptations that might make her time at work more accessible and comfortable. First, she asked for a device that she could use for drinking. As her arms were difficult to control, it was not feasible to secure anything to her laptray. Ongoing technology support was provided by one of the members of her team, a graduate student in biomechanics. He mounted a Camelback™ drinking system to the back of her wheelchair and attached a flexible copper lever to place the sipping spout within her reach. This system worked well, but required considerable effort to refill and clean. As the next, unrelated, modification was designed, a better solution was discovered for her drinking.

Due to the spasticity in Sonia's arms and the hyperextension in her fingers and wrists, she had difficulty maneuvering through doorways. This has led to the loss of fingernails, near sprains, and muscle strains. The simplest solution was to mount two vertically-oriented, curved posts to her laptray. She was easily able to place her hands inside of these restraining posts, away from the door frame, as she passed through the door. These posts were created using 1/2" x 12" PVC risers that were secured to the laptray via a 3/8" x 6" lag bolt. In the case of Sonia's right hand, the post was curved slightly by using a heat gun to soften the PVC. The PVC was covered with tube foam, and then wrapped with electrical tape. These posts served as a robust mount for Sonia's next drinking device.

The drinking adaptation was made from a standard cup holder, the type that attaches to the inside of a car window. The hook portion was cut away and the remaining frame was pop-riveted to a 6" length of 1" diameter PVC pipe. Two longitudinal cuts were made along the entire length of the pipe, effectively removing one-third of the PVC and creating a c-shaped clip, when viewed in cross-section. The c-clip was then warmed with a heat gun and spread open another 15% in order to increase its diameter. Sonia's large water bottle fits in this cup holder which then slides onto her left hand post. Twenty-four inch lengths of clear acrylic tubing were heated and bent to an appropriate angle for Sonia to use as straws.

Sonia's devices are not failproof and require occasional adjustment. Sonia, her co-workers, and her other support staff continue to notice items that can be improved by simply changing a fastener or relocating a component to a position that takes greater advantage of her muscle coordination. As Sonia increases her use of assistive technology, she demonstrates to others how much is possible with teamwork and creativity.

RESULTS

By developing a device that showcased Sonia's computer capabilities, the project staff was able to develop a rewarding job for Sonia in the field of her choice. The device was the lens through which potential employers could "see" past her disability onto what she was capable of doing. She has surpassed what anyone thought she would accomplish and much to her delight is now making a rewarding $5.00/hour compared to $3.00 a day at the sheltered workshop. By working 20 hours a week she now has enough money to purchase more than just the bare necessities and has achieved her dream of moving out of a group home and into an apartment of her choice. As Sonia recently stated, "Look how far I have come since I started this job! I feel like I am finally in the world and not in the institution." There has also been increased awareness by those around Sonia of her competence and emerging independence. She now feels that others take her opinions more seriously and can see past her limitations to the whole person she really is.

DISCUSSION

It is important to note that each successful device revealed more of Sonia's capabilities which led to the development of additional modifications and increased her independence at the jobsite. The following components were central to the success of this process. First, the transdisciplinary approach allowed for more creative brainstorming and utilized various types of available expertise. Second, with Sonia in the lead, the Tech Team was able to create a device that maximized her potential and was customized according to her needs and preferences. Third, the involvement and commitment of the manager and co-workers at Road Runner was critical in identifying the most essential aspects of her job. In addition, they provided feedback on prototypes so that Sonia would be performing duties important to the company, thereby making her a valued employee.

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DESIGN OF A UNIVERSAL SWITCH MOUNT

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ABSTRACT

Individuals with various degrees of motor impairments use switches to control electrical devices. Mounting these switches, onto wheelchairs and other fixtures has proven to be a complicated and costly task. The authors of this paper developed a design for a switch mount for Rosedale School in Austin, Texas that solves many of the problems currently encoutered by school's staff. This design mounts securely to most of the fixtures found at Rosedale and can be reproduced at the school's own wood shop for a total cost of approximately $40. Therefore, four times as many switches can be provided to Rosedale's students than what is currently available.

BACKGROUND

A person with a severe motor impairment of the types characteristic of cerebral palsy will find it difficult to live and work independently. However, technological advances are being made which enable these individuals to participate more fully in the community. Among these advances are adaptive switches which can be used to control any number of electrical items and can be operated by any part of the body [1]. Example switching functions include control of wheelchair speed and direction, operation of communication aids, computers, environmental controls, and other devices.

A variety of switches are available to meet the needs of people with motor impairments. For example, persons who have spastic muscle movements generally require durable switches, whereas individuals with hypotonia need switches that are sensitive to a light touch [2]. Still others, namely people who are paralyzed, benefit from switches operated by light or air (ibid.). The varied nature of these motor impairments inevitably results in switches of different shapes and sizes as well as in the need to position the switches in different locations and angles.

STATEMENT OF THE PROBLEM

Clearly, the problems that arise are: 1) how to attach different switches to a variety of fixtures (i.e., wheelchairs, tables, tumbleforms, etc.) that a person with cerebral palsy uses and 2) how to position the switches into any number of configurations. Several different approaches have been taken to solve this problem.

Figure 1: The Rosedale Switch Mount

The most common commercially-available switch mounts are produced and/or distributed through AbleNet, a company that specializes in adaptive devices. These mounts are costly, heavy, difficult to adjust, and tend to slip from their original position during use. As a result, people also create their own means of mounting switches such as using velcro, cardboard, microphone tubing, tape, and various other materials available to them. Although home-made devices solve the problem of affordability, they are often neither durable nor sturdy. Furthermore, because of their crude appearance, such mounts can detract from an individual's ability to be successfully included and accepted in his/her community.

The authors worked towards a solution to these problems by designing and developing an affordable and socially-acceptable switch mount that is durable, stable, easy to adjust and can be attached to a variety of objects.

METHODOLOGY

Armed with the original project statement supplied by Rosedale, the design team used traditional product design and development techniques, as explained by Ulrich and Eppinger [3] to create the Rosedale Switch Mount (RSM) shown in Figure 1. The team first gained a better understanding of the problem by conducting customer interviews at Rosedale. Through this process, the team was able to compile a list of tangible customer needs and to satisfy these needs with corresponding engineering requirements. Using Quality Function Deployment methods, a House of Quality (ibid.). was then created. The House of Quality illustrated the interrelationships between the customer needs and the engineering requirements and established their relative importance. The benchmarking information in the House of Quality also helped in constructing the list of target specifications.

The next phase of the design process involved a simplification of the primary task of the RSM and the determination of the energy, material, and information flows needed to accomplish this task. The design team divided the primary task into a series of basic functions, each having several possible solutions. The two primary functions of the RSM were clamping onto different surfaces and positioning the switch. The solutions were then combined into a multitude of possibilities to form the alternative designs. Using Ulrich and Eppinger's selection methodology (ibid.), the team selected several concepts.

DEVELOPMENT

Once the problem was thoroughly analyzed and concepts were selected, the authors built proof-of-concepts to determine the feasibility of their preliminary designs. First, the team reproduced a patent from 1950 (ibid.) which consisted of a series of joints, not unlike the vertebrae of a human, made out of wooden spheres with a steel cable drawn through them. The advantage of this concept rested in the fact that such an arm would be easy to use because the joints could be locked in one place by pulling the cable taut. But it was discovered that too much force was required by the user to lock the arm. Improvements could have been made by altering the surfaces of contact between each joint; however, doing so would have made the implementation more complex and difficult to manufacture. Therefore, this concept was rejected.

Figure 2: The "Tinker Toy" Concept

The authors then developed a concept based upon Tinker Toys and built a preliminary prototype out of wood (see Figure 2). This concept impressed the design team by its simplicity and by the similarity of its different parts. While producing the prototype, the tolerances for the joints were hard to predict using common wood shop tools, therefore a jig was manufactured to build the hinge discs for the next prototype (see Figure 3). The next step was to select the materials and determine the dimensions for each part of the alpha prototype.

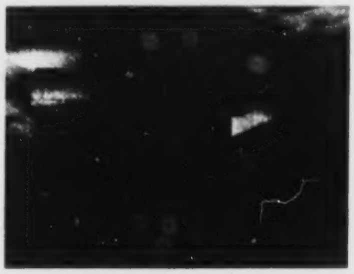

Figure 3: The Jig

Concurrently, the authors worked to solve the problem of attaching the switch mount to the fixtures used by the customer. The AbleNet clamp being used by Rosedale School at that time worked well but could have easily been improved with a better grip surface and an attachment for flat surfaces. Therefore, the team decided to purchase the AbleNet clamp and modify it to meet Rosedale's requirements. This decision not only eliminated any machining for the device, thus keeping the cost per unit low, but also enabled the staff members of Rosedale School to significantly improve the stability of their current switch mounts.

Developing the concept into a fully working alpha prototype involved engineering analysis, material selection, cost analysis, and safety issues. The critical function of the alpha prototype was the locking mechanism. Each joint had to lock three degrees of freedom: rotation of the extension, translation of the extension, and rotation of the hinge discs. It was important to select polycarbonate for the extensions in order to provide the flexibility needed to reduce the force at the joints and the clamp. The design team chose PVC for the joints because it was the most inexpensive and lightweight material that fulfilled the engineering and safety requirements. Rosedale School spends approximately $180 per switch mount and indicated that they would like to have the ability to purchase three times as many. Therefore, the authors decided to develop the product for under $60. As with any design, various safety concerns arose during the development of the alpha prototype; such as rough surfaces, sharp edges, and the possibility that the user's fingers could be pinched between the hinges. These issues were evaluated and resolved by the design team.

After testing the alpha prototype at Rosedale, the authors determined that more clamping force was required to keep the arm in place when a stronger students was using it. Because of the sharp edges on the circular knobs, the person adjusting the mount was not able to grip the knob tightly. Therefore, sufficient torque could not be achieved. As a result, bar knobs were implemented for the beta prototype. In addition, the team decided to use a stainless steel tube for the first extension in order to alleviate the excessive "bounciness" caused when using all polycarbonate extensions.

DISCUSSION

This paper presents the development of an affordable and reliable switch mount for people with dissabilities. The RSM clamps securely to wheelchairs, tables, desks and other fixtures and allows the switch to be configured to any desired position up to 26 inches away from the base. The final cost of the switch mount with the modifed clamp is approximately $40 and can be completely manufactured at Rosedale's wood shop. A fully illustrated fabrication/assembly plan and a user's guide have been provided to facilitate the implementation of the device. The authors have enabled Rosedale School to acquire four times as many mounts as they can currently afford which increases the ratio of switches to students in their classrooms. In addition, the device was designed with inclusion in mind, thus allowing it to be used at job sites and during social activities (without being obtrusive.) Furthermore, the Rosedale staff is enthusiastic about being able to produce more switch mounts in house and at an affordable price.

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RECYCLING FOR THE 22nd CENTURY

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ABSTRACT

The integration of people with disabilities into society is and will continue to be an important issue into the next century. One example of how this can be achieved is being demonstrated by a school named Rosedale. One of their programs involves recyclting of aluminum cans. This provides the students with the opportunity to ineract with society while learning skills that can be used in society, and generate income for themselves and the school. In keeping with these goals, the authors designed an aluminum can crushing device that was aimed at enhancing the abilities of the students.

BACKGROUND

Rosedale School, a member of the Austin Independent School District, is a provides students with disabilities a chance to "live, work, and enjoy life in our community [1]." The school also strives to demonstrate how providing students "educational opportunities and quality instruction [1]" in addition to care and love, will "increase their independence, improve their self-esteem, and [allow them to] experience a greater quality of life.[1]"

The Rosedale School currently provides students with opportunities to interact with their environment and the people around them through a variety of activities. One such activity involves recycling aluminum cans. This is intended to provide interaction and involve teamwork among a group of students. The role of the design group was to assist Rosedale by improving the current method and equipment used in the activity to increase the interaction and level of involvement of the students. The decision was made to redesign the current recycling process to accomplish this. The design team was committed to provide a safe, effective, and stimulating method for processing aluminum cans that would enable people with disabilities, at Rosedale School or elsewhere, to enhance their physical and mental development.

PROBLEM STATEMENT

Rosedale currently has a recycling process which includes cleaning, crushing, storing, and delivering the aluminum cans. The staff at Rosedale was not completely satisfied with the current process for a number of reasons. First, the current automatic crusher jams constantly which makes the process frustrating for teachers. It is crucial that the process be uninterrupted so that student interest can be maintained. Second, the current process required the teacher to assist the students more than was desired. This made it difficult for the students to be independently involved in the process. It was decided that a mechanism would be designed that would be more reliable and that would provide the opportunity for greater student involvement.

Time and manpower became a limiting factor during the concept selection phase of the design. After much deliberation within the design group, it was decided to narrow the design down to an aluminum can volume reduction system. The time and effort required to effectively improve on the entire can washing and volume reduction process was determined to be less than feasible. Effort was focused on designing a new "crusher" that would allow the students with varying abilities to be involved more than they are with the existing can crusher.

DESIGN

After determining a path and direction for the team, a product design and development methodology was employed as proposed by Ulrich and Eppinger [2]. The methodology involves a structured step-by-step method for creating a product based directly on needs expressed by the customer. The needs are interpreted based on interviews conducted directly with the customer(s). Once these needs have been interpreted and ranked, a Quality Function Deployment is performed which leads to generation of actual design concepts, engineering requirements, and technical specifications. Finally, a prototype is constructed to meet these specifications and needs.

The primary customers were determined to be students with disabilities and those who teach them and supervise their development. The team interviewed ten individuals including teachers, parents, physical therapists, people with disabilities. On-site observations of the current process in operation were also conducted. The interviews and observations provided the insight necessary to determine that the six most important needs were that the device should be safe, reliable, durable, easy to load, keep students interested, and not jam. In addition, two other issues were that the device be manufacturable by the staff at Rosedale, and cost less than $100 to build.

In order to achieve a design that focuses on the involvement and response of the students, it was necessary to analyze the needs and relate them to student involvement in the process. The device needs to be reliable so each can that is input into the device experiences a reduction in volume and exits the system in a repeatable and anticipated manner. Reliability directly relates to the ability of the design to maintain the interest of the students. Ease of loading is important to allow students with all levels of ability to use the device. Therefore, an entry point for the device that allows a margin of error would be beneficial. Lastly, one of the more important needs determined was that the device crush cans without jamming. The current machine jams approximately 20% of the time. The intent of the future design was to reduce, and possibly eliminate, any jamming that might occur.

Although the needs addressed above were important, manufacturability and cost issues were imperative to the success of the design. The capability at Rosedale is limited by the tools and staff available. The school has a small woodworking shop consisting of two staff members who build products out of wood and plastic in addition to performing simple electrical assembly. This imposed a large constraint on the design.

After determining the customer needs, the target specifications for the system were developed. These specifications were necessary in determining the guidelines for the design. These guidelines quantified aspects such as safety, forces, materials, and ergonomics.

Given these specifications, solutions were developed for each function of the device. These solutions were rated against each other to determine how well each one satisfied the customer needs and combined to form the overall solution. Next, specific solution principles were generated to find ways to achieve the generalized solutions. Once this was accomplished, the solution principles were scored against each other with respect to the needs. The results were summed and the concepts with the highest scores were chosen.

DEVELOPMENT

In the development stage of our chosen concept, a preliminary cost analysis was performed and the results were demoralizing. Since the staff at Rosedale were expected to be able to manufacture the device, a complex design had to be avoided. The solution, consisting of an electric motor, gear train, and a slider-crank mechanism, required a gear train that is complicated to manufacture and mount. Thus it needed to be a single unit which could be inserted into the system as is. The price of the gearbox alone was determined to be approximately $100, making the solution infeasible. The next solution, a lead screw mechanism, was also determined to be significantly over the allotted budget. Other similar solutions proved to be infeasible due to cost or manufacturability constraints. Finally, it was realized that modifying the can crusher currently in use at Rosedale would be most economically feasible. In addition, it supplied the drive mechanism, making the design manufacturable by Rosedale staff. With a rejuvenated spirit, the design team pressed on in this direction.

An Alpha prototype was then built to show the functionality of the device and to demonstrate the ability of the "retrofitted" design to satisfy the customers needs (see figure 1 below). It was also used to determine unforeseen problems that might occur.

After completion of the Alpha prototype, the design was reviewed. Jamming was still a major problem in the crushing chamber due to cans getting hung up on each other and not falling into the crushing chamber properly. Also, if a can was dented, it would not slide down the boxed chute to the crusher and would stall the entire process. The Alpha prototype also had not addressed the need to keep the students interested, ease of loading, durability, or safety. Therefore, a Beta prototype was constructed to eliminate the problems associated with the Alpha prototype and to satisfy the needs not addressed. (see figure 1 below).

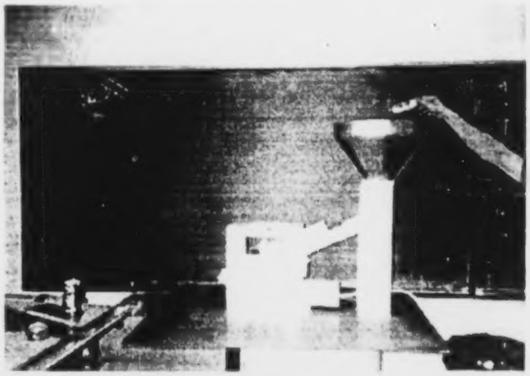

Figure 1 - Beta prototype

The Beta prototype operates as follows: A student manually pre-forms the can, the next student drops the can into a funnel that receives and channels it into the crusher, then another student enables the crusher via a push-button or lever switch. Finally, a student receives and stores the crushed can after it has been ejected.

When more than one can is dropped into the system, the first can falls into the chamber while the second sits on top of the can being crushed. The slider moves beneath the second can. The first can is crushed and falls out of the ejection port and as the slider returns, the second can falls down into the chamber. This was different from the Alpha prototype since it does not push the can out of the way, thus eliminating the need for the unreliable pushing attachment.

The Beta prototype addresses the customer's needs in many ways. The safety of the device was treated with priority and the following solutions were incorporated into the design. It is imperative that the crusher not operate when a hand is within the device. Therefore, the device has been enclosed so it is inaccessible unless the user remove the lid. A cutoff switch is attached to the lid so that when the lid is removed, no power is transferred to the motor. The geometry of the ejection port was also modified to make the crushing chamber inaccessible.

The reliability of the Beta to crush cans uninterrupted also increased tremendously. This prototype did not rely on the questionable pushing mechanism that the Alpha prototype required. Increased reliability of this device will lead directly to the satisfaction of students participating in the recycling activity.

The Beta also provided more involvement and stimuli than the Alpha. This was accomplished in various ways. First, the cans are dropped into a funnel. The funnel allows students with varying physical abilities to perform the insertion. Exact orientation and placement of the can is completely unnecessary. Also, the funnel is constructed of sheet metal which creates audible stimuli. Second, the Beta provides an option when turning on the crusher. A choice can between pushing a simple button or pulling an adjustable force lever. This feature allows students with varying physical abilities to operate the device. The Beta also keeps students more interested than the Alpha prototype would by providing more visual and audible stimuli. The sound of the motor running, the sight and sound of the can being crushed, and the can entering and exiting the device all provide a significant amount of stimuli.

Durability is an important issue because large forces are required to crush a can, and also because rough usage is inevitable. The parts that have the largest forces applied to them have been made easily changeable. This allows the staff at Rosedale to provide the can recycling activity to the students often without being interrupted by faulty equipment as has been the case in the past.

DESIGN EVALUATION AND TESTING

The device was tested to determine how well it satisfied the customers. The reliability of the device to successfully crush and eject the cans was found by testing thirty cans in the system. The reliability of a can entering the crushing chamber correctly was found to be 93% for undamaged, 90% for mildly damaged , 90% for medium damaged, and 83% for severely damaged cans. The can ejection reliability was determined to be 96%. This was a great improvement over the existing device for both ejection and jamming within the chamber.

Further evaluation of the design will be done by taking it to Rosedale and testing the device by letting the students use the device to crush cans. This will enable the design team to determine how well the device keeps the students interested and how easy it is for them to load. It is expected and hoped that the students will be very enthusiastic about using the device. It is also desired that the device perform its intended purpose and provide the students with feelings of accomplishment and increased interaction with their surrounding environments.

A training and maintenance program will also be developed .

DISCUSSION AND CONCLUSIONS

An aluminum can crushing device was designed to adapt to and enhance the abilities of the customer. The students of Rosedale can now more effectively recycle their cans and not only receive the benefit of interaction with people and things around them, but also generate income for themselves. The design team focused on modifying an existing design to improve and enhance the reliability, durability, ease of loading, and its ability to keep the students interest. These needs were met while keeping within budget and designing the device so it is maintainable by the staff of Rosedale School and keeping the cost around $100.

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ARTIST'S CHOICE: A "GRASP AND RELEASE" MOUTHSTICK FOR ART TOOLS

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ABSTRACT

This paper will present a new dynamic, mechanically operated mouthstick (Artist's Choice) designed for a graphic artist with C3-C4 quadriplegia, that will allow for independent interchanging of standard markers and paintbrushes of various diameters without the use of holders or tips.

BACKGROUND

An artist's tools are the means by which he is able to express himself and communicate via the canvas. For an artist with quadriplegic involvement a mouthstick may be the primary means by which he accesses these tools.

Currently, commercially available mouthsticks either hold only one pencil or pen, or use appliance holder tubes (end tips) for interchanging various tools. The materials are secured in individual tips which slide or secure onto the end of the mouthstick. The Modular Mouthstick Kit (available from Therafin Corporation), the Attachment Handler and Aluminum Telescoping Mouthstick (both available from Extensions for Independence) are three examples of mouthsticks using interchangeable appliance tips. The appliance tips for these mouthsticks are generally small, approximately the size of a standard pencil, and limit the size or diameter of the materials that can be used.

While the mouthsticks allow for interchanging materials, the choice of materials is limited. Markers and paintbrushes (of various diameters or sizes) may not fit standard mouthstick holders or tips and thus may be excluded from the artists choice of tools. This presented a problem for one man (J.G.) a graphic artist who needed a mouthstick that would allow him access to multiple materials and color choices.

J.G. is a 29 year old male who with C3-C4 level spinal cord damage from an automobile accident (less than a year ago). Prior to his injury J.G.was educated as and working as a graphic artist. He was referred to the Assistive Technology Unit by his occupational therapist for fabrication and customization of the Modular Mouthstick Kit (available from Therafin Corporation) for use with the computer keyboard and for drawing. After fabrication of this mouthstick the client noted the mouthstick provided him limited access to art tools as well as difficulty in seeing the tip on the end of the straight mouthstick. As a graphic artist, J.G. is used to experimenting with multiple materials, most often markers and needs access to multiple color choices for design layouts. His request was a mouthstick that would provide him a access to a full range of media.

DESIGN CRITERIA

With input from the client the following design criteria were established:

- Will allow commercially available markers to be used with minimal modification.
- The mouthstick will allow the user to independently interchange multiple color choices.
- The mouthstick will be as light as possible for ease in use and manipulation of the tools.
- An angled end to the mouthstick is preferred by the user to see the tip of the tool for drawing.
- Safety and health issues- intraoral use, saliva control and ease of cleaning.

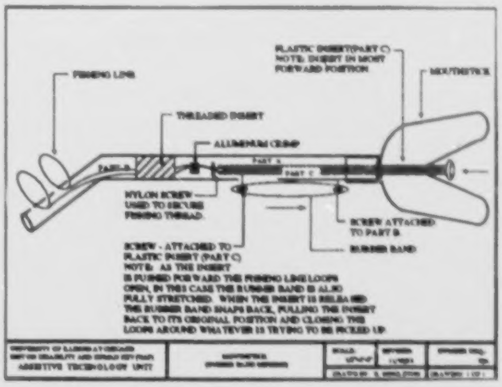

PLASTIC INSERT (PART C)
NOTE: INSERT IN MOST FORWARD POSITION
FISHING LINE
MOUTHSTICK
THREADED INSERT
ALUMINUM CRIMP
PART B
PART A
PART C
NYLON SCREW USED TO SECURE FISHING THREAD
SCREW ATTACHED TO PART B
SCREW - ATTACHED TO PLASTIC INSERT (PART C)
RUBBER BAND
NOTE: AS THE INSERT IS PUSHED FORWARD THE FISHING LINE LOOPS OPEN, IN THIS CASE THE RUBBER BAND IS ALSO FULLY STRETCHED. WHEN THE INSERT IS RELEASED THE RUBBER BAND SNAPS BACK, PULLING THE INSERT BACK TO ITS ORIGINAL POSITION AND CLOSING THE LOOPS AROUND WHATEVER IS TRYING TO BE PICKED UP
ASSISTIVE TECHNOLOGY UNIT

Diagram A

ARTIST'S CHOICE

RATIONALE

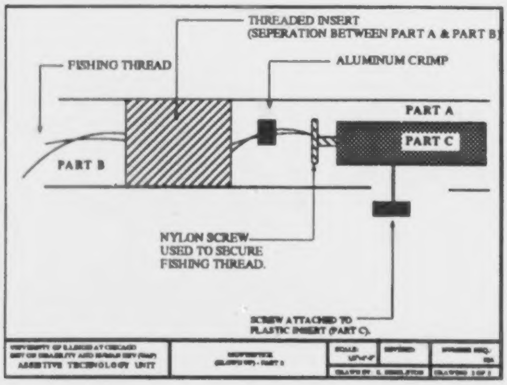
J.G. uses the computer for graphics and layouts, but is accustomed to designing from free hand drawings. He would like to use a mouthstick to draw out his ideas and incorporate these ideas into his layouts. The commercially available mouthsticks were insufficient in meeting his requests (design criteria) therefore a customized mouthstick was needed.

DESIGN AND FABRICATION

A lightweight, plastic mouthstick with a spring component for "grasping and releasing" the desired tools was designed. The mouthstick uses a rubberband component and fishing line to secure the desired tool. A plunger, when pushed with the tongue, widens the loops to release the tool and hook onto another tool. The loops tighten around the tool when the plunger is released. (See diagram A)

Fabrication of the mouthstick is as follows:

Two pieces of 3/8" polystyrene tubing are attached via a threaded insert, piece A and piece B (see diagram B).


THREADED INSERT
(SEPERATION BETWEEN PART A & PART B)
FISHING THREAD
ALUMINUM CRIMP
PART A
PART C
PART B
NYLON SCREW USED TO SECURE FISHING THREAD.
SCREW ATTACHED TO PLASTIC INSERT (PART C).
ASSISTIVE TECHNOLOGY UNIT

Diagam B

Piece B: Piece B is heated and bent at a 45 degree angle. A 1' x 1" x 1/8" piece of kydex is heated and bent into a c-shape, approximately 3/4 inch diameter (size of most large markers). Two sets of holes, four total, are drilled into the kydex and tubing at an angle.

Piece A: A 1 1/2" x 1/8" slot is milled into piece A approximately 2" from the top of the tubing.

Piece C: (a 1/8" diameter polystyrene tube) One end is tapped for a 4-40 binding head nylon screw. A small hole is drilled into the head of the nylon screw to allow one strand of fishing line to be threaded through it.

Two strands of 75 pound strength fishing line are threaded through the four holes on piece B. The fishing line is threaded in a U shape and forms a loop that is approximately 1 1/2" in diameter. The four ends of the fishing line are crimped together above the threaded insert with a small piece of aluminum tubing. Three of the four ends are trimmed close to the top of the aluminum crimp. The fourth end is threaded through the head of the nylon screw of piece C, linking the head of the screw to the top of the threaded insert. The end of this strand of fishing line is trimmed and heated to form a ball locking it in place. The nylon bolt is screwed into piece C. (See diagram B).

Piece A is connected to piece B with a 10/32 threaded insert. A custom fit mouthpiece (available from Independence Technologies), previously heated and formed to the client's mouth, has a channel drilled through the neck and the base of the U on the mouthpiece to allow passage of piece C. The mouthpiece is then secured onto piece A. A rubber cap is placed over the end of piece C to form the plunger.

Two holes are drilled and tapped, one into piece C and one into piece A (see diagram A) for insertion of two 4-40 round head machined bolts. A rubber band tightened around the bolts provides the spring action necessary for activating the loosening and tightening of the fishing line loops.

DISCUSSION

A commercially available mouthpiece is adapted to address safety and health issues. To control for saliva collection a cap at the end of the mouthstick can be removed and the inside of the mouthstick cleaned with running water and allowed to air dry.

In addition to the mouthstick a turning palette was designed. The turning palette holds markers and other tools of various sizes. The turning component allows the user greater access to a number of tools within the user's accessible range. The diameters of the selected markers were increased to allow for ease in removal. A V-shaped stand was fabricated to hook the cap for removal.

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ARTIST'S CHOICE

To allow the user access to both smaller diameter and larger diameter tools two mouthsticks were provided. The angle of the tip and length of the mouthstick were adjusted on delivery.

In addition to providing access to commercially available markers and a variety of independent color choices the mouthstick allows the user to "grasp" the tool at different points increasing or decreasing the length of the mouthstick for access to a greater range when drawing.

Further design considerations include a means of incorporating a "grasp" of both large and small diameter art tools into one mouthstick as well as a means for the user to independently change the angle of the drawing tool.

SUPPLIERS

American Science and Surplus
5696 N. Northwest Highway
Chicago , Illinois
(312) 763-0313

Item	Unit
1) 3/8"OD, 7/32" ID Polystyrene tubing	1' length
2) 3/16" Polystyrene Tubing	1' length
3) Rubber cap	1/ each

Independence Technologies Corporation
9427 Rosmarin Way
Montpellier, MD 20708
800-644-4482

Item	Unit
Mouthpiece	$59.95/ea

Mc Master Carr Supply Company
P.O. Box 4355
Chicago IL 60608
(708) 833-0300

Item	Unit
4-40/1/4" Binding head nylon screws #9500A106	$5.62/ 100

Hardware Store
4-40 round head machine screws

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SIG-15
Information Networking

Assistive Technology On-Line: a World Wide Web Server for Assistive Technology

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Abstract

This paper describes progress on a new World Wide Web server devoted to Assistive Technology (AT). This service, called *Assistive Technology On-Line* (http://www.asel.udel.edu/at-online), has been designed to provide useful information on assistive technology to a broad audience and to serve as a gateway to other information services that may be of interest to the AT community. Its information is organized along two major dimensions: 1) Information type (e.g., organizations); and 2) Technology type (e.g., AAC). In addition a number of tools have been implemented including *forms* for external users to add information, a *search engine*, and a *calendar manager*. The current system while far from completed has a substantial amount of information and has recently been announced in a variety of forums. While AT On-Line has officially been in existence for less than a month, it has had a relatively high access rate and has received positive user comments via a feedback form.

Background

The wide availability of information resources related to Assistive Technology is recognized as beneficial to consumers, service providers and other practitioners in the field (3). In recent years, a greater amount of information has been available electronically including databases, multimedia CD-ROMs, and bulletin board services (2). One channel for information dissemination that has experienced unprecedented growth for the disability interest community is the Internet. Services such as electronic mail, newsgroups, gopher and the World Wide Web (WWW) provide a wealth of information and a means for individuals to easily communicate on a variety of issues.

Services such as the *Cornucopia of Disability Information* (6) provide a wide range of information on disabilities. In addition, there are hundreds of newsgroups and listservers focusing on disability issues (4). Finally, Internet-based resources that focus specifically on topics in Assistive Technology are beginning to appear (7). Despite this, there is still a need for an Internet-based information service that is both specific to Assistive Technology and comprehensive in its approach.

Approach

Assistive Technology On-Line is a new WWW server that focuses specifically on AT. Its major design goals are the following:

- Provide useful AT information to a broad and varied constituency that includes consumers, service providers, researchers and others interested in the field of AT.
- Serve as a gateway to other information providers especially those specific to AT.
- Provide a place where people and organizations can post useful information such as meetings and announcements.

In addition to these overall goals, concerns such as general "ease-of-use" and accessibility of materials are of primary importance.

Design and Development

Organization - To date, the focus of AT On-Line has been primarily on overall structure and content. There were numerous discussions with potential users to determine what would be the most useful organization of material. The resulting structure offers two immediate ways to access information from the home page: by *Technology Type* and by *Information Type*.

Technology Type contains categories that relate to specific assistive technologies (e.g., prosthetics) or functional area (e.g., education). It currently consists of the following:

- Adaptive Toys/Games
- Augmentative Communication
- Cognitive Aids
- Computer Access
- Education/Learning
- Environmental Controls
- Home Modifications
- Mobility
- Positioning and Seating
- Prosthetics/Orthotics
- Recreation/Sports
- Robotics
- Self-Care
- Sensory Aids
- Transportation
- Worksite Modifications

Information Type consists of categories that cut across the field such as policy or categories that represent a specific type of information such as publications. It consists of the following categories:

- Devices
- Services
- Government Policy (including funding)
- Federally Funded Programs relating to AT
- Research
- Organizations
- Papers and Publications
- Index of Internet Resources on AT & Disability

This approach to organization has a number of advantages and disadvantages that result primarily from the fact that information may be duplicated within each major group. For example, a description of ISAAC (the International Society of Augmentative and Alternative Communication) appears both under the *Organizations* category and under the *AAC* category.

The primary advantages of a two-way organizational approach are:

- Greater coverage of information. For example, if technology type were used exclusively, it would be difficult to find suitable locations for information that cuts across the field (e.g., RESNA)
- Grouping of information that can appeal to a wider range of user goals. For example, a user new to the field might want to look at the range of available information on a specific technology, whereas an expert user looking for the RESNA phone number might move more quickly through the alphabetical listing.

The disadvantages are:

- The increased work-load of creating and maintaining duplicated information—although in the medium of the Web, information that appears duplicated often is a result of cross-links;
- A potential for user confusion because of multiple navigation paths to the same information. However, this is always a concern when designing hypermedia.

This organizational structure will continue to evolve and be subject to user feedback as well as analysis of usage statistics. Currently many of the categories are unfilled, but that situation will certainly change through the addition of information by both project staff and external users.

Page Format - The implementation of pages within AT On-Line is driven by existing Web design guidelines including those for general usability (5) and guidelines to maximize accessibility (8). In particular, the use of graphics in the system is restrained and when used is supplemented with alternate descriptions.

AT On-Line uses a consistent page layout. Each page consists of a heading, a navigation strip above and below the main body of information, and an acknowledgment section at the very bottom. The navigation section consists of small rectangular graphics (with alternate text) that are labeled *Home*, *Up*, *Search*, *Add*, and *Help*. *Up* navigates to the next level above in the document hierarchy; *Home* traverses back to the home page; and *Help* offers information about the navigation buttons and other system features. *Search* allows the user to search the database, and *Add* allows users to add information to AT On-Line. These features are discussed in the next section.

Additional Tools - There are a number of additional tools that have been developed for the server that supplement the basic document collection. The *Search Facility* enables users to locate information throughout the whole server by entering key words. The search engine returns an ordered list of pages that contain instances of the key words. This tool was implemented using SWISH (Simple Web Indexing Systems for Humans), wwwais, and Perl scripts.

The *Calendar Manager* provides a listing of events such as conferences and meetings relevant to Assistive Technology and Disability. Each page shows all events that are occurring for a given month. If the number of events becomes sufficiently large, search forms will be added that will let a user specify some criteria (e.g., location) for the event. The calendar manger has been implemented in C++ and Perl.

Finally, the *Add* feature is an extremely important component of AT On-Line. Given the scope of the AT field, it is virtually impossible for any individual or organization to comprehensively produce all relevant information. Consequently nearly every page in AT On-Line has an *Add* button that links to a context-sensitive form designed for the particular area of the server (e.g., the calendar). User-submitted material is edited and verified by project staff and subsequently added to the server.

An information exchange forum is another tool of future consideration. This tool would be similar to listservers or newsgroups which allow discussions between users. FAQs (frequently asked questions) could be stored and accessed. Furthermore, some type of consistent referral system could be established for specific areas of information.

Evaluation

Although the World Wide Web has gained tremendous popularity there is still a need to determine its efficacy as an information channel particularly for AT professionals and consumers. As our server continues to evolve, we intend to evaluate it further and use these evaluations to refine its design. The server has been officially operating for approximately one month. Advertising its presence on the Internet has only begun in the last week. Despite this, there has been a surprising amount of traffic.

From November 13, 1995 to December 5, 1995, there have been 2,305 pages accessed from outside our organization. A "visit" is defined as any number of page accesses from a unique address on a given day. While this metric is not 100% accurate, it is a reasonably close measure of the site activity. During this period of 22 days, AT On-Line has had 462 visits. Of those 462 visits, 400 of them are from unique addresses. This indicates that 62 visits are either repeat visits or visits from the same site but by a different person.

Several individual users have come across the server and have sent us their comments. All responded with very positive feedback encouraging this effort and the provision of more information. There backgrounds were: AT provider, parent of a child with a disability, and an Occupational Therapist.

Further evaluation would be useful and we eventually would like to run a statistical analysis of web visits to our site and its particular sections over a longer period of time. Another thing that could be of benefit would be to generate survey forms that could offer us more feedback with respect to particular issues. Questions on the survey could request the user's purpose for accessing AT On-Line, whether the information they sought was available, and how they learned of our site.

Discussion

The World Wide Web as an information medium is nothing short of phenomenal. Consider that AT On-Line, which is in its infancy and has had virtually no advertising is averaging approximately 21 visits a day. In comparison, a paper describing AbleData published in June 1994 reported 5,960 information requests or 16.33 per day (1).

We hope that AT On-Line will be a useful information resource on the Internet. To do so, it will be important that its structure and content continue to evolve to reflect trends on the Internet. For example, as other groups continue to publish information on specific AT topics such as the *Assistive Technology Funding Page* (6), we will need to reevaluate our coverage of the area and perhaps point the reader directly to other servers. However, it is important to understand that there is ample room for a variety of editorial viewpoints on similar materials: this is part of the essence of the Internet.

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INCORPORATING DIGITAL VIDEO INTO A SOFTWARE BASED EXPERT SYSTEM

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ABSTRACT

In ways not possible using text, video can show motion (1, 2), motivate viewers (2), and convey emotion (1, 2). Digital video is video that can be generated, edited, stored, or displayed on a computer. As one component in a computer software program, digital video offers a flexible communication tool and an eye-catching technique to help meet project objectives.

The Computer-Aided Wheelchair Prescription System is a computer software expert system designed to assist rehabilitation professionals prescribe wheelchairs. One project goal is to help rehabilitation professionals view wheeled mobility in a broad and flexible context—encouraging them to seek out and identify a range of activities and environments that make up the mobility needs of their clients. Digital video was one method used to illustrate a comprehensive concept of wheeled mobility.

BACKGROUND

The Computer-Aided Wheelchair Prescription System (CAWPS) software is a computer software expert system intended to assist rehabilitation professionals during the wheelchair prescription process. Designed to organize the enormous amount of information that must be considered when prescribing a wheelchair, CAWPS provides a framework for identifying and inputting information about a client's physical needs, anticipated environments, and personal goals. Based on questions generated by the computer software, CAWPS creates an ideal wheelchair profile for an individual client. CAWPS then compares this ideal wheelchair to existing wheelchairs. CAWPS is a tool to help clients and rehabilitation professional make the best and most informed wheeled mobility choices possible.

OBJECTIVE

One goal of the CAWPS program is to encourage rehabilitation professionals to consider as many alternative definitions of wheeled mobility as possible. Ideally, CAWPS will serve to remind those of us who prescribe wheelchairs that, for our clients, wheeled mobility may include a wide range of activities and environments. One client may need safe mobility over rough terrain at a work location, while another client with similar physical abilities may need a lightweight wheelchair for sports.

The expert prescription system contained in CAWPS provides a detailed method to identify the personal goals and anticipated activities of a client. However, project coordinators also wanted an additional method to encourage rehabilitation professionals to consider how the mobility needs of their client may change in different environments and over the life of the wheelchair. Digital video was chosen because of its ability to show movement (1, 2), motivate (2), and convey emotion (1,2).

Digital video provides an opportunity to demonstrate and educate in ways not offered by written text. Video can present a great deal of information quickly and efficiently. In the CAWPS software, digital video will be included at key decision points in the prescription process. For example, when rehabilitation professionals are prompted with questions about the recreational interests of their client, they will have the opportunity to view short clips showing individuals using wheelchairs during recreational activities.

METHOD/APPROACH

Including video in a software program can be labor intensive and ultimately an expensive process. Although the process will vary somewhat depending on the project undertaken, including video in the CAWPS software involved the following steps:

1. *Identifying specific goals for including video in the project.*
   For the purposes of the CAWPS software, digital video clips were included to demonstrate the wide range of activities and environments in which different types of wheeled mobility equipment may be used. In addition, it was hoped that digital video would present a dynamic and personal view of wheelchair use—one that couldn't be as effectively presented by textual information..

2. *Identifying the potential sources of video to meet the established goal.*
   To meet the our video goals, we were able to identify several commercially produced videos containing footage of various activities and environments.

3. *Obtaining releases from the owners of the video copyrights.*
   After selecting the video segments we hoped to use, we needed to identify the copyright holders for the video and obtain permission from them to include short video clips in the CAWPS software.

4. *Securing the necessary computer hardware and software to digitize analog video for computer presentation.*
   To capture and digitize analog video we needed video equipment to play the videos, as well as a combination of computer hardware and software to capture, digitize, and play back the digital video. Fortunately, we had access to more than one computer system. After experimenting with capture and playback on different machines—both Macintosh and PC platforms—we used a Macintosh Quadra 950 with 24 MB of RAM and a Radius Video Vision video capture card to capture the video for use in the CAWPS software.

5. *Edit the video to the desired length and content.*
   We used Adobe Premiere 4.0 during the initial video capture as well as to edit and prepare the final video clip.

6. *Compress the video clip and prepare for cross-platform playback.*
   Cinepak compression in Adobe Premiere was used to compress the edited version of the video. Cinepak was chosen because of its cross-platform (3, 4) and CD-ROM (3) playback capabilities. Adobe Premiere 4.0 was also used to "flatten" the video, a necessary step allowing Macintosh video files to be played on an IBM compatible machine. Flattening a digital movie converts Macintosh files, which are stored as two separate resource forks of data, into a single linear file playable on either platform.

7. *Adding text captioning to the video.*
   After the videos were completed and playing on both platforms, captioning was added as a text track below each video. The text track was added to allow end-users with impaired vision to access the information presented by the video in a text format (5). Digital video content, because of its generally small window size and relatively low clarity is not readily accessible by users with impaired vision. Adding a text track to the video is one technology that can make the video content accessible to users through the use of display enlarging software or screen reading software. Movieplayer 2.0b2 for the Macintosh was used to add the text track and save the video file in its final form.

8. *Test the video for playback on both platforms using computers with a range of speeds and monitor capabilities.*
   In their final form the videos were tested on a range of computers to see how different monitors, CPU speeds, and CD-ROM speeds affected the playback quality.

DISCUSSION

As the technology becomes more refined and multimedia computer systems more widely available, digital video is being used as a part of more computer based presentations. However, digital video as a communication tool still has its drawbacks.

The data files required to store digital video can quickly become very large. Although the size of the video files will vary, based on the capture method, the content of the video, and the compression/decompression software used, ten seconds of digital video can easily require 1Mb or more of storage space. The larger file sizes of digital video make CD-ROM storage and retrieval more feasible than storage on traditional floppy

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disks. For storage and retrieval of the data involved, CAWPS software will be distributed on cross-platform CD-ROM.

Another potential drawback of digital video can lie in the quality of its playback. As the quality of the "average" computer system improves, the quality of digital video playback will also improve. Bigger faster computers with fast CD-ROM drives and high quality video displays will obviously do the best job showing digital video, but what about the owners of older systems? If the software or presentation you are preparing may eventually be distributed to a large audience of end-users, it is important to consider that all of the users may not have state of the art computer systems. Consequently, as we have done in CAWPS, if important information is presented by video it should also be available in another form for those users who may not have sufficient video playback quality to show important details.

However, despite its drawbacks, digital video still offers an opportunity for software developers, educators, or anyone needing to present a great deal of specific information quickly and efficiently. Digital video is an excellent way to present movement oriented information (1, 2), convey emotion (1, 2), and motivate users (2). In addition, digital video can allow user control over the video playback. By allowing users to stop, back up, and replay the entire video or sections of the video it allows the user to select and guide their own information seeking. Users can select the information they want and begin to organize its presentation in a way that makes the most sense to them. Although still a relatively new technology, the use of digital video in computer software is likely to continue to grow.

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USER SATISFACTION OF COMPUTER-BASED TRAINING IN ASSISTIVE TECHNOLOGY

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ABSTRACT

In order for professionals to apply assistive technology principles and solutions in collaboration with the individuals they serve, these professionals must have a knowledge base of assistive technology devices and assistive technology services. The Department of Occupational Therapy Education at the University of Kansas Medical Center received a special projects grant to develop a learning tool, an interactive, multimedia software program, to assist professionals in acquiring this information. One measure of this learning tool's success is to look at the user's level of satisfaction with the learning experience. More than 170 individuals have used this learning tool and provided formal and informal feedback. Results of this feedback indicate that using this learning tool is a satisfying method of acquiring knowledge about assistive technology.

BACKGROUND

Project ASTECH is an interactive, multimedia CD-ROM software program that teaches novices about assistive technology devices and assistive technology services in the areas of computer access, augmentative communication, and environmental control. The goal of this project is to provide an alternate, effective, convenient, and satisfying method of educating special educators and related service personnel (e.g.,occupational therapists, physical therapists, speech language pathologist).

OBJECTIVE

The objective is to present information that validates Project ASTECH as a satisfying means for individuals from varying professional backgrounds to learn about asssitive technology devices and services.

METHOD/APPROACH

Data regarding user satisfaction with a computer-based learning tool was collected using two appoaches. Project staff collected data from field testers who viewed sections of the software program. Field testers completed a survey and were given the opportunity to write comments regarding what they found satisfying and dissatisfying about using the computer software program. Project staff also conducted research studies in which the user completed satisfaction scales. The Attitude toward Computer Assisted (CAI) Instruction Tool uses a bipolar adjective scale (1).

RESULTS

Field tester data: Sixty field testers provided feedback on the portion of the software that introduces the learner to categories of assistive technology devices and gives examples. Fifty-nine percent of the field testers had never used an interactive computer program in their formal or informal education and 96% agreed or strongly agreed that they would recommend this program to others. All of the field testers (100%) agreed or strongly agreed that the software program had educational value and 98% agreed or strongly agreed that they enjoyed being an active part of the learning process. Field testers noted in their written comments that they liked the flexibility to go where they wanted in the program,the review questions with immediate feedback, the Kids in Action feature (i.e.pictures of children ov various ages and diagnoses using devices), and the video and audio segments. Of the 50 field testers who viewed the assessment portion of the software, 100% agreed or strongly agreed that the program had educational value, 92% enjoyed being an active part of the learning process and 90% would recommend the program to others. Testers liked the flexibility to pick answers they wished to explore and thought the graphics were "great" and correlated well with the text. In the area of dissatisfaction, individuals in both groups commented on the inabilitiy to watch certain videos and animations and the slowness of the program.

Research participant data: Twenty four occupational therapy students and 24 therapists learned to program an augmentative communication device and completed a questionairre two weeks after their participation had ended. Seventy one percent of the students and 86% of the therapists preferred using an interactive computer program over the instruction manual for learning how to program an augmentative communication device. Therapists reported feeling more satsified when using the computer program as the learning tool, regarless of role, age and familiarity with common technology (VCR, computer, mouse).

Twenty six occupational therapy students participated in a pilot study, part of which was included completing the Attitude toward CAI instruction tool. Students gave the highest ratings to the adjectives useful, creative, and easy while also indicating that the computer-based learning was impersonal.

DISCUSSION

Most individuals who have used this multimedia, interactive software program to learn about assistive technology devices and services are satisfied. Portions of the software with the most interactive components and application of information elictied the most favorable responses. There were few negative responses. Some of the factors that influence negative responses, such as the impersonal nature of the learning, can not be changed. However, other negative responses can be addressed. Users must have a computer with the minimal hardware requirements to run the program or else they will experience frustration in the slowness and/or inavailability of portions of the software.

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INTERNET AND ASSISTIVE TECHNOLOGY: LOCAL COMMUNITY NETWORK

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ABSTRACT

The Assistive Technology Discussion Forum developed in Washington State is an electronic discussion group focused on assistive technology (AT) and disability related issues. This electronic network provides consumers, professionals, service providers, and other community members with a convenient way of connecting with resources, and sharing information and experiences. We present here strategies to increase the level and breadth of participation by consumers, professionals, service providers, and others. We also discuss the training and technical assistance required to support the forum and ways for participants without access to the Internet to participate. Finally, we review efforts to reach out to various groups of consumers.

BACKGROUND

The capacity of electronic networks to link people and information resources without reference to time and place is more than a matter of convenience. In many cases it is the only way that people living in rural areas, mobility limitations, speech impairments, and other disabilities and circumstances can link up with other people and information resources around disability issues. This networking can facilitate increased awareness of and access to creative solutions, imrpoved advocacy, and increased quality and availability of services.

OBJECTIVES

By creating a dynamic local electronic discussion group we sought to achieve the following objectives:

(1) Connect people with AT information, resources and services, as well as with knowledge, and experiences of others.
(2) Identify gaps in local resources and services, and facilitate the creation of new resources.
(3) Provide a safe, convenient, and constructive forum for consumers and service providers to share their perspectives on AT devices and services.
(4) Help consumers to become more effective users of electronic resources, increasing access to information, advocacy resources, etc.
(5) Create a group of consumers who are effective users of electronic resources to serve as role models and trainers for others.
(6) Create a tool for mobilizing and organizing local communities around critical advocacy issues.

APPROACH

As we developed the forum we considered the following factors:

a) The forum must be developed in the context of providing useful and practical information.
b) People without computers, modems, and/or internet access must be access to the forum
c) Consumers (especially those using alternative access to computers) must be provided with initial on-site technical support and training. Continued on-going technical support and training may be necessary.
d) Training needs to include teaching consumers how to use electronic networks to access information relevant to individual needs, beyond AT or disability issues.
e) A community outreach effort must be mounted to attract the "critical mass" of consumers and professionals.

METHOD

The Assistive Technology Resource Center (ATRC) located at the University of Washington in collaboration with a local service provider established the electronic discussion forum to facilitate increased access to AT information and services in Washington State. Three access points were established:

a) A USENET newsgroup (topic) named

"wash.assistive-tech" was created. In this system, messages are collected by topic and stored/swapped by computers called "news servers". To access a given newsgroup, it is generally necessary to have an account on a system that "carries" it (each server recognizes the existence of only a limited number of the thousands of topics under discussion all over the world). Special "newsreader" software of some sort is also required.

b) A "listserv" list (automatic e-mail distribution system) was set up on the U.W. mainframe computer. Any message sent to the list address is automatically posted to the USENET group, in addition to being copied to all the other "subscribers" of the mailing list

c) The ATRC advertises the fact that it will act as a go-between for those who don't have computers or otherwise wouldn't be able to participate.

Participants. We recruited eight consumers of AT who already owned and used computers to serve as "community consultants on the forum. We offered them modems and training in exchange for their participation on the forum and asked that they serve as "mentors" for other participants joining the forum.. Being life long AT users, the community consultants had extensive knowledge of the local service delivery system. Because speech and/or communication devices are laborious and slow, the community consultants had found that their past advocacy efforts had been difficult and were excited about the potential efficiency afforded using electronic information systems. A university student knowledgeable about software and hardware was hired to visit each community consultant and install a modem, set up communication software, and train community consultants in the use of electronic mail and networks. Three to five technical assistance visits to each community consultant were necessary for training, dealing with incompatibilities of software and hardware, access issues, and programming macros to increase the automation of the on-line system. When programming a communication system was necessary, a speech pathologist donated her time to help.

Although we eventually succeeded in solving almost all the technical problems encountered and provided Internet access to each community consultant several consultants have not yet contributed a posting to the forum. We attribute this to the individuals' limited literacy skills, to the cumbersome on-line systems, and to the difficulties in defining the role of a community consultant.

A network of AT professional consultants was also created and members were asked to screen the postings on the group and respond to inquiries. Many professionals were already users of electronic mail and had access to the Internet although some technical assistance was still necessary to help them participate in the electronic discussion.

Outreach efforts. The effort to involve more consumers, professionals, and service providers in the electronic discussion has been ongoing and predates the establishment of the forum. Demonstrations, presentations, newsletter articles, fliers, and word of mouth have all been employed to increase participation. Technical assistance continues to be available to professionals and consumers. The ATRC regularly uses electronic networks to solicit donations of used modems and distributes those as necessary.

The I&R Connection

The forum has been tied in to the information and referral (I&R) network operated by the Tech Act grant in Washington State. Inquiries received by the ATRC are routinely posted to the discussion forum and any responses posted to those inquiries are passed on to the callers in any format requested (by phone, fax, computer disk, Braille etc.). This approach serves three main functions. First, it facilitates the electronic discussion by continually providing new inquiries. Second, it offers a means for tapping into the information and knowledge available in the community while ensuring that the AT Resource Center is not perceived by the community as an information gate keeper. Third, it serves as a convincing argument for the usefulness and practical value of electronic networks, convincing some I&R callers to consider the viability of on-line resources.

RESULTS

The AT Discussion Forum was established in June 1995. There are currently an average of four postings/messages a day to the group, and this number continues to rise. Typically, postings come from individuals with disabilities and professionals seeking advice on identifying, obtaining, and funding assistive technology devices and services. Various disability and commercial groups post inquiries seeking personal experiences people with various disabilities encounter (for instance, difficulties encountered in air travel or when using computer software). Community events announcements are posted along with postings by people offering and seeking employment opportunities. It took four months to generate the first one hundred messages, but it took only one month to generate the second hundred. The first one hundred messages were generated mostly by the founders of the group and by members of the network of consultants and AT professionals. The majority of the messages in the second hundred postings were generated by the general public. The discussion up to date has been productive, constructive and informative. A number of individuals have been connected with information and resources. For instance, an individual seeking a source for renting gel batteries was able to locate a vendor offering the service, a person with limited financial resources was able to find a volunteer to repair his computer, a list of shareware/freeware software useful for disabled users was compiled, participants learned about opportunities for talking with their legislators, etc.

DISCUSSION

The process of establishing and managing the discussion forum highlighted several important issues.

(1) Creating a vehicle for electronic exchange of information (whether it is a bulletin board, listserv distribution list, or a USENET newsgroup) may not bring in broad participation and discussion. To secure initial consumer participation, technical assistance must be available to all that are not familiar with or are unable to select, install, and set up a modem and appropriate communication software package, and especially to consumers who use alternative computer access.

(2) It is important to recognize that participation in an electronic discussion requires a sufficient level of functional reading and writing skills, accompanied by sufficient computer skills (including word processing), and knowledge about networks (how they are organized, how they function, the network etiquette etc.). Negotiating the Internet environment requires particular skills that are usually not acquired automatically and need to be taught.

(3) Getting on line, and overcoming the initial difficulties in participating in an electronic discussion requires persistence and continuing technical support and training. It is helpful to assist community consultants with determining different ways in which electronic networks may enhance an individual's life.

(4) Hardware and software problems the community consultants experienced clearly pointed out the need for creating a support network of (perhaps) volunteers who could help with computer repair. Otherwise, the founders of the group and the providers of the training will remain the only known source of technical assistance, creating a dependency on systems that may not be permanent arrangements.

(5) Freenets are a terrific resource and a very important way of assuring access to electronic networks to a large part of the population that would otherwise be left behind. However, due to limited funds and resources, the operating system used by the Seattle Community Network (freeport) proved to be very cumbersome and difficult to navigate. In addition to that, SCN does not provide an 800 number for those calling from outside the larger Seattle area, leaving a large part of the state without access to this resource (plans are under way for every public library to provide access to SCN, but it is unclear how long it will take). SCN users also experience a frequent busy signal, which combined with a 45 minute limit per session, discouraged participation.

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SIG-17
International Appropriate Technology

DEVELOPMENT OF TRICYCLE PRODUCTION (DTP) IN DEVELOPING COUNTRIES

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ABSTRACT

This paper describes the approach, execution and results of the project 'Development of Tricycle Production (DTP) in developing countries'.
This project has been carried out by the Delft University of Technology, in close cooperation with four Asian organizations. The project focussed on the improvement of the design and production of handoperated tricycles. A Tricycle Production Manual has been made, for use by other tricycle producing organizations in developing countries.

BACKGROUND

There are over 500 million more or less disabled people in the world today; 80% of them are living in developing countries. As a consequence of disease, accident or war many of these, mostly poor, people have partly or completely lost their freedom of movement. This seriously hampers their opportunities in education, (finding) work and participation in social life. They are house bound and are completely dependent on other people.
The possession of a tricycle can give a large number of them the possibility to travel to the city for selling tickets or going to work.

A tricycle is a hand operated vehicle, that is propelled by means of a chain- or cranklever mechanism and is suitable for driving long distances, under bad road conditions and for the transportation of goods.

All over the world small workshops in developing countries produce these tricycles, in many different designs. These tricycle designs need improvements: they are often uncomfortable for the user, not suitable for the local situation and difficult to produce. Imported tricycles from Western countries are often too expensive and not suitable for use under the average conditions in developing countries. Usually, they also lack spare part which makes repairation difficult or impossible.
The DTP project has been carried out by the Centre for International Cooperation and Appropriate Technology (CICAT) in cooperation with the Faculty of Industrial Design Engineering (FIDE), both of the Delft University of Technology (DUT), for, and in cooperation with four organizations in Asia. The project was executed in the period from December 1992 up to May 1995 and was funded by the International Aid Foundation (SHIA), through the Swedish International Development Authority (SIDA).

TARGET GROUPS

At the start of the project two target groups were formulated:
1 The tricycle producing organizations
2 The tricycle users

At first, the project focussed on the cooperating tricycle producing organizations (in this paper called 'counterparts') and usersof tricycles; The workshop for Rehabilitation and Training of the Handicapped (WORTH trust) in India, Sarvodaya Economic Enterprices Development Services (SEEDS) in Sri Lanka and McKean Rehabilitation Centre (MRC) in Thailand. The Bavi Orthopaedic Workshop (BOW), Bavi in (north of) Vietnam was partly involved.
Secondly, a tricycle user targetgroup was defined as: disabled people in developing countries who cannot walk, but who can use both arms well. Most of these users might be paralysed, have a leg amputation (caused by (war)accidents or deseases) or have had polio.

OBJECTIVES AND OUTPUTS

The main objective of the DTP project was to significantly improve the (full) participation and equality of disabled people in developing countries in social and economic life. To achieve this goal, the project focussed on the improvement of hand operated tricycle designs for disabled people and the development, improvement and stimulation of the local production of tricycles in developing countries.

The following operational goals have been formulated for the project:

1 To carry out a full inventory of and comparative research on a wide scope of tricycles (being) used in both developing and industrialized countries.
2 To carry out comparative research on tricycle production processes, mainly concerning those of the cooperating organizations in the DTP project (in Thailand, Sri Lanka and India).
3 To optimalize design, test, analyze and optimize the prototypes of the parts, sub-constructions, complete tricycles and production processes, taking into consideration local workshop possibilities.
4 To optimalize the products, production processes and workshop management of the counterparts on a individual base.
5 To develop a Tricycle Production Manual.
6 To organize a counterpart exchange programme.

As expected outputs of the project, the following have been formulated:

- Survey **reports** on ergonomical aspects, production processes, performance of existing tricycles and workshops in developing countries
- New **prototypes** of parts, sub assemblies and complete tricycles as well as appropriate production processes for new prototypes
- **Training** of local engineers, technicians and managers on designing, testing and optimalization of products and production processes and on workshop management
- A **Tricycle Production Manual**, consisting of:
  - main features of the tricycle
  - 2D, 3D production drawings and exploded views (parts, sub- and total assemblies)
  - guidelines for the adjustment of the tricycle
  - other relevant production and background information

EXECUTION AND RESULTS

Planning and Approach

In the project a multilateral approach has been chosen, which means that all involved organizations are aiming at joint cooperation. Although the organization and communication in such a project might be difficult, the advantage is that the organizations can share their problems and solutions, thus balancing the respective contributions of the partners. Moreover, by adopting such an approach, the final results represent a broad variety of tricycle design and production know how, leading to better opportunities for its later international dissemination among other tricycle producers.

In the project the CICAT/FIDE combination has acted as an intermediairy, also planning overall activities in several phases and providing background information. During the project, the results of each phase were discussed in seminars, each planned in and organized by the counterpart's organizations.

Inventory and Programme of Requirements

During the first phase, information has been collected and analyzed in order to formulate a programme of requirements for the new tricycle. Information on user aspects, particularly ergonomics, was new for most of the (technical oriented-) participants. At a first seminar, as main problems of the existing tricycles the following were assessed:

- instability during driving
- bad driving efficiency, caused by wrong transmission ratio's and heavy weight
- wrong dimensions and position of the seat and propulsion mechanism
- difficulties production accuracy (partly caused by a lack of skills and partly by a lack of good quality of materials, tools and machines)
- too high costs.

Industrial Design Engineering Training

After the first seminar a product development training was organized for the participants in the project in Chiang Mai, Thailand. The main aim of the training was to introduce a systematic, incremental approach to product development, to provide the elementary procedures of problem solving and in particular to focus on mechanical engineering aspects.

Prototype Selection and Technical Drawings

The third seminar, in India, was combined with a three week workshop for the production of two prototypes of the two selected designs: a symmetric and an a-symmetric tricycle design. The whole project team agreed with the selection of the asymmetric design for further development, mainly because this design was easier to produce. Apart from these activities, research had been carried out in order to gain a better understanding of the target group of the envisaged Tricycle Production Manual. Amongst others it was found that the drawings should be preferably 3-dimensional, that pictograms would only be understandable on a realistic level and that too much textual explanation should be avoided.

Production of 0-series and User Tests

In the next phase, the Dutch team completed the technical drawings and each counterpart produced and tested 5 new tricycles. In Figure 1, a sketch of the new tricycle and some of its new aspects has been given.

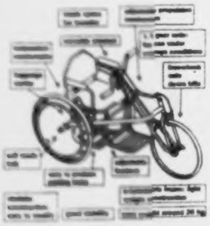

Figure 1. The DTP new tricycle design

The results were evaluated in the fourth, and last, seminar in Sri Lanka. First conclusions are that the design is a good compromise of many important requirements (on production, use, costs etc.). Particularly, the ergonomic aspects of the tricycle were considered to be outstanding. The high tolerances of the dimensions and the modularity of the design make the tricycle easy to produce and adjustable to local demands and wishes. Allthough the adaptation of the totally new design next to the existing tricycle design will take time, the counterparts are now seriously looking for possibilities to introduce the new design on the market. In Sri Lanka for instance, the new tricycle is being promoted with articles in local newspapers and even in television broadcastings.

THE TRICYCLE PRODUCTION MANUAL

During the last phase of the DTP project, the Dutch team worked on the development of the manual. The manual contains mainly drawings and hardly any text, in order to make the information accessible to users with different languages and levels of education. The drawings include measurements relevant for the production and assembly of each part. The dimensions of the tricycle are based on the anthropometric data of the Asian population; people with a body length of 1.50 meter up to 1.75 meter.

EVALUATION

The project has been finalized succesfully, leading to the expected outputs mentioned above. However, the new tricycle design and the associated Tricycle Production Manual should considered to be only the first steps in the stimulation of a systematic tricycle development and production in developing countries. Local and regional marketing of the new design and continuous research on its further improvement are the necessary next steps. The success of the DTP project has been based on both the selection of motivated participants and an excellent cooperation between all parties involved. In this respect the fostering of a strong commitment by the workshops's management; knowledge/ confidence building through seminars and workshops, and the involvement of universities, disabled organizations and NGO's have proven to be crucial factors for a good result. Finally, it is worthwhile mentioning that the Delft University of Technology is looking for further opportunities to disseminate the results, specifically the Tricycle Production Manual, among workshops and companies in developing countries by means of appropriate national and international organizations.

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DESIGNING A SHORT-RANGE WHEELED MOBILITY DEVICE FOR WOMEN IN INDIA

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ABSTRACT

The design of appropriate rehabilitation technology requires the careful consideration of numerous interdependent design parameters. The technical, functional, economic, and cultural environments in which the technology will be used must be well understood and accounted for if a design is to be successful. This paper presents a case study of these issues within the context of rural and low income India, wherein novel 'low-height' mobility devices for disabled women were designed and fabricated. Detailed design analysis from both the cross-cultural and cross-professional perspectives was performed with a major emphasis on user feedback throughout the design process. Using this design philosophy, a path was ultimately negotiated between the ideal and pragmatic dimensions of rehabilitation technology development.

BACKGROUND

"Mobility is critical to the fabric of human society. It is essential for almost all aspects of daily self-care, work and play. Without mobility, the barriers to participation are immense" (1). It is the effort to remove these barriers to participation which has led to the design and development of better mobility devices. Although great technological advances in rehabilitation technology have been realized in the West, these advances are not always easily transferable to developing countries. To account for this difficulty, effort has been spent on developing 'appropriate technology' - technology which considers the economic and cultural environments in which it will be used. Although progress has been achieved, the need remains staggeringly high.

It has been estimated that of the some 20 million potential wheelchair riders in developing countries, less than 1% currently use any such device (2). Specific to India, the need for wheeled mobility devices is thought to be approximately 3-4 million. Furthermore, current estimates of Indian wheelchair production are on the order of only 20,000 units per year (3). Clearly, given the large supply deficit and low domestic production rates, a great need for all types of mobility devices will remain well into the next century.

Logically, different types of mobility devices are appropriate for different activities. The type of device required is a function of the task at hand, the physical distance which must be traversed to perform the task, and the specific functional needs of the user. For example, a hand driven tricycle (a long-range device) would be appropriate for a rider with good upper body strength to travel several kilometres. For shorter distances, a wheelchair (a mid-range device) may prove to be more useful. For activities within and around the home, however, especially in cultures where many activities are traditionally performed on the floor, neither device is appropriate. In these situations, 'caster-carts' or 'floor scooters' are sometimes used. In India, many types of caster-carts are presently being used, especially in urban areas. Hof has stated that, "there is a need for thorough evaluation and dissemination of good caster-cart designs" (4). The authors of this paper concur, and have identified the potential for 'new' designs.

OBJECTIVE

The objective of the project is to design and develop a novel mobility device for use by women in rural and low income India. This device is intended to assist the user in performing activities of daily living within and near the home and to therefore fulfill a need not well satisfied by wheelchairs, tricycles or other existing mobility devices. Specifically, the new device is intended to assist the user in performing those tasks which are traditionally performed at ground level. To this end, the device will most evidently differ from traditional wheelchairs by physically keeping the rider near to the floor. The design concept is based on existing 'caster-carts' and is labeled a 'low-height short-range' mobility device.

The specific objectives of this paper are threefold: (i) to demonstrate the complexity which arises from the numerous interdependent design parameters associated with the design of appropriate

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technology, (ii) to discuss the design method used to successfully address this complexity, and (iii) to present the results obtained from the short-range mobility device design process.

METHOD

Orpwood suggests that the design of rehabilitation technology involves the consideration of numerous complex biological variables, such as anatomical, physiological and psychological variables (5). To this list could be added the list of technical, functional, economic and cultural variables associated with appropriate technology design. To efficiently address these numerous interdependent parameters as they pertained to the Indian mobility device project, a design methodology adapted from Orpwood was used.

Initially, interest was directed at the layout of the device. Numerous simple sketches were developed showing different conceptual layouts that were possible within the restrictions imposed by technical factors such as anthropometrics and ergonomics, and functional factors such as the required ranges of motion deemed necessary from a task analysis. From these preliminary sketches, a preferred layout was decided upon through collaboration of technical experts (mechanical engineers) and functional experts (occupational and physical therapists). A mock-up (a simple three-dimensional model which emphasizes the proposed geometry) was then constructed based on the preferred layout. To evaluate this first design, a focus group was conducted to obtain critical feedback. The participants in the focus group were chosen for their experience with disability and Indian culture. From this feedback, numerous additional sketches were produced to reflect the latest input. Again from these sketches, a preferred layout was collaboratively obtained. Using this new layout, technical supporting features such as the frame, seating platform, and wheels were designed. A working model was fabricated which incorporated these new design aspects. This working model was then used as a starting point for further work with our Indian design colleagues. Using a similar iterative approach, five additional working models were designed and fabricated focusing on various functional, cultural and aesthetic aspects of the design. These six working models continue to be field-tested in India to obtain further specific user feedback (Figure 1). This information will be used in conjunction with several technical refinements to develop a 'final' design prototype.

RESULTS

The ultimate physical result of this project will be, of course, the final mobility device prototype. However, several important general results have been obtained thus far in the design process.

The perceived need for 'low-height short-range' mobility devices in rural and low-income Indian communities was confirmed. Visits to these communities with the devices generated great interest and excitement. The women quickly adapted to the new devices and felt that they would prove very useful in allowing them to participate more fully in the community.

Importantly, it was found via user and therapist feedback that the design should be kept as simple as possible. This had originally been assumed from a technical perspective in order to minimize manufacturing and maintenance costs. That the same philosophy resulted from the functional perspective suggested a major point: the simpler the device, the greater the acceptance. Numerous optional design features were discouraged (folding mechanism, baskets, adjusting seating platforms, etc.). The users felt that many of these additions would interfere with the device's utility by possibly decreasing range of motion and by rendering the design aesthetically 'menacing'. Similarly, the users wanted their device to be as small as possible. It was felt that a small device would detract less attention from the user, and would make it more maneuverable in the small spaces typical of their homes.

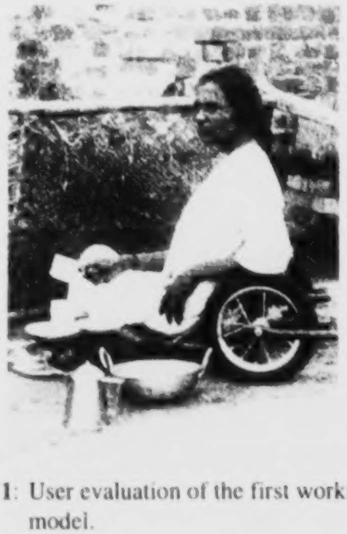

Figure 1: User evaluation of the first working model.

Finally, and arguably most importantly, it was found that user feedback was often contradictory to professional opinion. This was true not only in the most obvious scenarios (e.g. a Canadian engineer making poor assumptions regarding Indian activities), but also in less obvious situations (e.g. an Indian designer making poor decisions regarding aesthetic preferences). Without fail, the user much preferred simplicity over complexity, even at the expense of a certain degree of functionality.

DISCUSSION

The traditional engineering design process hinges upon the set of requirements which the system is designed to satisfy. This set, usually called the list of specifications, is typically well defined from the outset and is therefore relatively simple to test for compliance during the subsequent creative phases of the design process. A successful design is defined as one which satisfies all of these requirements or specifications. In complex situations, however, this traditional process suffers severe inadequacies. Not only are the specifications for a complex system difficult to define and evaluate, they often are interdependent variables which are impossible to evaluate individually. To overcome this problem, the *relationships* between the design specifications must be defined in addition to the design specifications themselves. A successful design in this case requires not only that all the specifications be satisfied, but that the functions describing the relationships between the specifications be accurate and representative. Evaluation of this system is possible when these relationship functions are quantitative and objective, but proves to be extremely difficult when they are qualitative and subjective. The design of appropriate assistive technology, especially in a cross-cultural perspective, is an example of such a complex design problem.

For example, in the mobility device project under consideration, it was specified that the device must be light, strong, inexpensive, functional, and aesthetically pleasing (amongst others). Although it is possible to put specific measures on weight, strength, and cost, it is difficult to know exactly *what* specific values for each would result in the best device. Furthermore, it is practically impossible to put a meaningful number on functionality or aesthetics - both extremely important design parameters. Even if this quantification were possible, the functions which describe the relationships between the five factors would be too complex to practically model.

In order to address this complexity, a non-traditional approach to design was necessary. In this project, a practical low-cost method was used with great success. This method emphasized user feedback by continually approaching the user with simple, focused models which were ***designed to stimulate user feedback and not necessarily to immediately provide a 'best' design.***

Finally, given the cross-professional and cross-cultural nature of appropriate technology design, collaboration at all stages by the users, the Indian designers, and the Canadian therapists and engineers was crucial for a successful result. It is appropriate in this assistive technology development project that the ultimate decision-making authority is the technology user.

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COLLECTING DATA IN A DEVELOPING COUNTRY

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ABSTRACT

The recent introduction of SIG 17 to RESNA reflects a growing interest in the field of international appropriate technology. When designing assistive technology for persons with disabilities (PWD) in a developing country, the Western designer is faced with many challenges. Strategies commonly used in the West must be modified or abandoned in search of approaches acceptable to the local culture. This paper will look at strategies, methods and considerations in collecting data to determine users' needs and design parameters in a developing country. In this paper "researcher" refers to the person(s) responsible for gathering the data.

BACKGROUND

A search of the literature resulted in no structured or consistent guide appropriate for collecting data related to design parameters in developing countries. However, the fields of cross-cultural research, rehabilitation engineering, and occupational therapy provide a relevant and valuable foundation.

Cross-cultural data collection or research can be defined as a goal-oriented interaction between people from two or more cultures (1,2). Cultural differences present challenges not otherwise encountered in the data collection process. Researchers must be aware of, and account for differences in beliefs and values, styles of verbal and non-verbal interaction, and the sense and use of time and language. The application of Western methods of information gathering to non-Western contexts may also present difficulties as many people of the developing world (elites or villagers) do not understand or appreciate the concepts of evaluation, measurement, or anonymity. Using multiple data collection strategies as well as multiple data sources may resolve some of the problems associated with cross-cultural data collection, and improve the quality of the information collected. Involving host country residents in the research process is suggested as a means of coping with cultural and language differences, and may provide guidance in selecting appropriate research methods. If the project is to be sustainable and hence successful, host country partners must have a vested interest in it. (1,2,3,4,5).

Traditionally, the development of assistive technology relied heavily on the knowledge and experience of rehabilitation professionals. The literature now reflects growing support for involving consumers in the design process to maximize the "success" of the design and minimize device abandonment (6,7,8). The PWD is a key player within the design team and all participants must endeavor to recognize the importance of this role. Orpwood (7) recommends introducing a simple model to the potential user at an early stage to elicit feedback and advice on the design. He feels that only this approach will yield an appropriate user-technology interface. A similar strategy has been suggested when designing products for use in a foreign context, to ensure they fit both the functional and cultural needs of the individual or population (9,10,). The consumer based approach is also in keeping with the philosophy of community based rehabilitation and client-centred occupational therapy research and practices (11,12).

STATEMENT OF PROBLEM & APPROACH

A recent project proposed to design an appropriate mobility device for women with disabilities living in rural and low income communities in India. The researcher was responsible for collecting data on the users' needs and design parameters. Due to the complex nature of assistive technology, the overall approach to data collection needed to be: 1. holistic, 2. reliant on the skills and expertise of various people, 3. adaptable to diverse situations. A literature search did not provide information relevant to the task until other disciplines were consulted. The project in India gave the researcher valuable on-site experience and insights, and the opportunity for first hand trial of strategies and methods proposed in the literature. The following data collection strategies, methods, and considerations are a combination of academic findings and in-the-field experiences in India.

DISCUSSION

Who

Partners: For an international technology project to be successful, the literature advocates a collaborative approach (3,4,5). The partnership should facilitate a sharing of information between countries, and the project must be beneficial to all. It also must use the skills and strengths of team members in a complimentary fashion to create a holistic approach. The PWD is a key partner, and other members may contribute skills from the fields of occupational therapy, ergonomics, engineering and/or product design. For the mobility device project, the team consisted of a Canadian occupational therapist and an engineer pursuing graduate studies, and in India, women with disabilities, an occupational therapist, a product designer, and design students. Host country partners are typically associated with government or non-

Governmental Organizations working in the area of rehabilitation. They can provide insights into cultural and ethical issues, and the political and bureaucratic climate and systems. Partners may identify potential users, act as translators, and facilitate entry into a community by way of introducing the researcher to PWD. A true partnership approach will ensure that host country partners have a vested interest in the project and the skills to ensure its sustainability when Western partners move on.

Translator: Sensitivity must be used in choosing a translator, for in many cultures their gender, ethnic background, and religion may impact on the success of the interview. For example, using a local translator of the same gender as the PWD will ensure the comfort level of the PWD and family, therefore promoting a free exchange of information. Prior to interviews the researcher must educate the translator such that s/he has a sound understanding of the project, is clear on her/his role, and knows exactly how the data will be gathered. Merryfield(2) warns researchers not to assume their English is the same as that of the host country or translator, as there are many "English languages."

PWD: Many persons with disabilities in developing countries will not be listed with standard rehabilitation organizations or Non-Governmental Organizations. To identify potential users, one must be willing to rely on word of mouth and local assistance, such as asking local people if they know of any other PWD. This is sometimes called "snowball-" or "network sampling" (14).

Researcher: Prior travel to the country in which the project will be taking place may help sensitize the researcher to the culture, enable her/him to assess the feasibility of the project, and provide opportunities to develop partnerships. An extended stay within the culture allows for general observations of culture, availability of materials, manufacturing options, aesthetics etc. An easy going attitude, flexibility, and determination will benefit the researcher, who must alsobe aware of any cultural and professional biases s/he brings to the project and strive to set them aside. For example, not all cultures value independence (13); it may more appropriate for a family member to assist with, or perform a task, than to rely on an assistive device. The researcher also must be aware of what effect her/his gender and status as a Westerner may have on the PWD and the community's response to questions (2,13). Participants' answers may be based on what they think the researcher wants to hear, not what they truly believe. This is commonly referred to as the Rosenthal effect.

Where

Lack of literature on PWD in developing countries, as well as the diversity of culture, geography,and assistive technology needs, forces the researcher to gather data "in-the-field". Getting to these locations may be very difficult, depending on one's expectations. Unpredictable events such as natural disasters or war may hinder or prevent the journey. Since maps are commonly not available, one must be prepared to ask for directions throughout the journey, sometimes from a number of people, to ensure a consensus on the correct direction. Home addresses are often vague, consisting of a family name, the village, and perhaps a statement describing the location of the home i.e. "across from school". Arriving in the village in search of a particular person, the most efficient strategy is to request a helpful community member to accompany you in the car to show the way.

How

There are many methods for collecting information. Due to the brief nature of this paper, only the 4 most relevant methods and considerations have been outlined.

Interviews: Because of high rates of illiteracy in developing countries, especially amongst PWD, a data collection method requiring written responses is inappropriate. Interviews are often the most efficient and culturally appropriate method for gathering information. A qualitative interview style, such as the "general interview guide approach", allows for exploration when new or unfamiliar issues arise while providing some consistency for the efficient gathering of information (14). It is up to the individual researcher to determine which type of interview is most appropriate based on the type of information required and the interviewer's skills. It is both difficult and often culturally unacceptable to interview PWD in isolation. Arriving in a village or slum the researcher is commonly surrounded by interested family members, neighbours and community members. It can be difficult to obtain uncontaminated opinions in developing countries because the living style is often communal and crowded (15). Interviewing the PWD, family and other community members in a group session is in keeping with their cultural method of communicating and sharing information. The benefits of interviewing a group includes drawing on multiple opinions and experiences at once. Unfortunately, the presence of others may intimidate PWD's and influence their responses. Women with disabilities are often difficult to interview as men may not allow them to be questioned, or will act as their spokesperson.

Observations: To determine the user's functional needs it is necessary to observe activities which the assistive device is intended to enhance or perform. Because many of the activities are alien to our culture, it is essential they be observed and recorded in situ. This also allows for task analysis, including a break down of physical movements, tools, and posture necessary for performance. Photographs provide an accurate depiction for future reference.

Photographs: Still photographs provide "objective" visual data which accurately depicts a reality at a specific point in time (15). Photographs serve four potential purposes. First, they may be used to supplement and clarify data collected using other methods i.e. photographs of a woman cooking may confirm a written description of her working posture. Second, photographs may be used independent of any other data i.e. a photograph of a stove enables one to conceptualize the challenges faced by the PWD in performing cooking activities. Third, taking and leaving photographs of the PWD and family greatly enhances rapport, and is a much appreciated "reward" for participation in the project. Finally, the photograph provides a medium by which to concisely and accurately convey information to others, especially upon returning home. Videorecording can be a culturally invasive but very accurate data collection strategy, especially for recording movement. Host country partners may have insight into the appropriateness of using this technique.

Other: People with disabilities in rural or low income communities often have never seen, heard, or thought of the technology you would like to provide them. Therefore, it is essential that questions relating to their needs, the assistive device, or future technical demands, be kept simple and direct. The introduction of a simple model may present difficulties, especially if all aspects of the device are not in working order i.e. it was built to show proportions. Photographs, sketches or verbal descriptions are often difficult to conceptualize. Whenever possible a full scale working model of the assistive technology should be shown to ensure the PWD clearly understands what is being discussed. If attempting to elicit feedback the PWD may require a long learning and/or trial period, due to inexperience and unfamiliarity with such equipment. For example when the researcher was in India and presented a new mobility device to PWD's unfamiliar with wheelchairs they were unable to learn to propel, steer or turn the device within the normal expected period of time.

Collecting data on users' needs and design parameters is an essential component to ensure the development of appropriate technology in the area of assistive technology. This paper reflects the lack of research into strategies, methods and considerations for such data collection in developing countries. As we move into the 21st century further exploration in this area is necessary to insure the success of future international assistive technology projects.

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DEVELOPMENT OF A COMMON LANGUAGE TO DESIGN A TRICYCLE FOR PHYSICALLY IMPAIRED PERSONS IN DEVELOPING COUNTRIES

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ABSTRACT

The project 'Development of Tricycle Production (DTP) in developing countries' was aimed at the design of tricycles that could be produced, maintained and used locally.

This would contribute to the participation of disabled people in developing countries in their social and economic life.

The Delft University of Technology carried out this project in close cooperation with four Asian organizations, the 'counterparts 'which already produce mobility aids.

Early in the project it was understood that establishing a common design language would be vital for communication. This paper describes how this common language was established by conducting a design exercise during which a tricycle for children was made.

BACKGROUND

Of over 500 million more or less physically impaired persons today; 80% are living in developing countries. As a consequence of disease, accident or war many of these, mostly poor, people have partly or completely lost their freedom of movement, which seriously hampers their opportunities in education, (finding) work and participation in social life

Many of them would be helped with appropriate means of transport, e.g. a wheelchair or a tricycle. Although many developing countries do have facilities to produce these mobility aids, the demand by far exceeds supply. Imports from abroad could contribute partly in this supply. However the problem with these imported products is that they are often too expensive and not suitable for use under the average (much worse) conditions in these countries (e.g. bad roads, dust etc.) and that there will be the problem of spare parts.

It is generally recognized that continuous provision of mobility aids can, on the long term, only be guaranteed when based upon local production.

A lot of work has been done already to stimulate and support local production by Ralf Hotchkiss of ATI in the USA in co-operation with several small workshops in Latin America. They designed a wheelchair, that can be produced with fairly simple tools and local materials in most developing countries. With it they published a production manual. With regard to tricycles a similar development focussed on developing countries has not yet taken place.

In developing countries wheelchairs and tricycles are being produced at different scales, although small-scale production seems to be the dominant mode.

CICAT (Centre of International Co-operation an Appropriate Technology acquired a grant from SHIA (Swedish Organization of Handicapped International Aids Foundation) to design a tricycle that can be produced and maintained in developing countries in co-operation with local workshops which are active in the production of mobility aids [1, 2].

This project was conducted together with FIDE (Faculty of Industrial Design Engineering) of the Technical University of Delft (The Netherlands).

OBJECTIVE

In general, when designing any product, the designer should know the user and the circumstances the product is used. This also applies to a tricycle and its production manual. In order to be able to communicate local producers of wheelchairs a first objective was to establish a common language.

APPROACH

In many developing countries local organizations are involved in the production of tricycles, wheelchairs and other equipment for the handicapped. Several of these organizations have made it clear that they are looking for technical support in the field of improvement and production of these transport means.

Up to now most of CICAT's (project) activities in the field of wheelchair and tricycle production have taken place in direct contact with organizations in South and South-East Asia

For practical reasons the project was focussed on cooperation with three Asian organizations described below. The choice for this being that these organizations are already producing tricycles and/or

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wheelchairs or other mobility equipment for the handicapped; they are all situated in the same region and finally they are familiar with CICAT.

Next to this CICAT-Transport had also informal contacts with and/or information on various other organizations (in Asia, Africa and Latin America) which might be willing and suitable to act as a counterpart at a later stage.

It was decided to co-operate with: (1) Workshop for Rehabilitation and Training of the Handicapped (WORTH), Katpadi, Tamil Nadu in India (2) Sarvodaya Economic Enterprises Development services (SEEDS), Ambalangoda in Sri Lanka and (3) McKean Rehabilitation Centre (MRC), Chiang Mai in Tailand.

Apart from the fact that they are located some thousands of kilometers apart in different countries, with different languages and cultures. Also working conditions and technical knowledge differed widely.

As these particulars were foreseen in the planning of the DTP project, seminars were included. The objectives were threefold: 1 understand in the capabilities of the counterparts; 2 develop a common language with respect to design and to the design of aids to physically impaired people and 3 to design, together with the counterpart a tricycle that could be produced in developing countries. In all three seminars were planned:

1 Develop a common language and give insight in the design process; start of the development of a tricycle for physically impaired people. This two week seminar was held together with the department of Mechanical Engineer of the Chiang Mai University in Thailand

2 Further jointly development of design work done by the counterparts and to discuss the results of the work at the FIDE (The Netherlands) and to visit small companies which produce mobility aids. This seminar took two weeks.

3 A three week workshop during which two distinct prototypes of a tricycle were made and tested. This workshop took place in India at WORTH.

RESULTS

The first seminar was centred around a design exercise during which a children's tricycle had to be designed. During this exercise also (morning) lectures were given by lecturers from both the Chiang Mai University and FIDE on theoretical subjects related to the construction of wheelchairs.

In all six members of the counter parts participated in this seminar.

The morning lectures were centered around components and related subjects, like:

frame—statics, types of loads, stress and strain, strength of materials, forming and joining of steel tube and sheet metal;

steering/braking—vehicle mechanics, steering geometry, principles and construction of brakes;

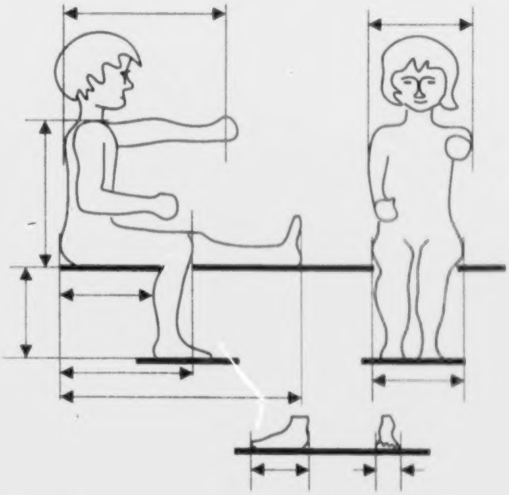
propulsion—principles of motion, work and energy, principles and construction of transmission, mechanisms;

user interface—ergonomics, paraplegic, polio and amputee patients, symptoms, specific problems, therapies, prevention of problems, adjustments and supports.

Design Exercise

It may sound strange to use a children's tricycle as design subject as such product is so much different from a wheelchair. The reason for not taking a tricycle for handicapped persons as the subject of study was threefold: as all participants work already in the production of tricycles, it was feared that discussions would too easily be centred around particular designs of the participants and thus hindering an open mind to the underlying principles when designing a tricycle for handicapped people. Also it would be very tempting for the participants to jump to conclusions that merely would be a choice for existing solutions decided upon in the past. (This is not to say that these solutions are without value, only that their merits should again be weighed against other solutions).

The participants had to do some home work: take measures of their own child (or any other child they knew between 5-8 years of age), as it was the intention to design the tricycle for that child. The measures are indicated below:



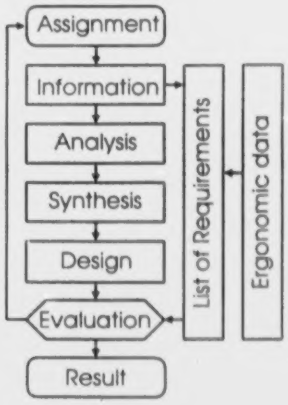
Dimensions of children's tricycles are distinct from tricycles for (handicapped) grown-ups. Apart from the overall size, also relative dimensions are different so there is no opportunity to fall back on rules of thump. On the other hand: properties of such a children's toy resemble a tricycle for handicapped persons in that there is a seat, footrests and a handlebars, of which the relative positions have to positions are dictated by body dimensions.

At first ideas had to be generated. It was demonstrated here, in the form of rough sketches, that many different sorts of tricycles are possible. After applying an evaluation with help of a first issue of a List of Requirements LoR), the best ideas were selected. These ideas were further elaborated to technical sketches with actual dimensions. Here the scale models that the counterparts had made of 'their' child were used to position seat, pedals and handlebars correctly. (It was pointed out that children grow, so that the tricycle had to be adjustable).

Calculations proved to be difficult, however with help of the staff, solutions were found to establish the dimensions of the main parts. It was demonstrated clearly that through calculation light and strong enough constructions can be made. Also during this stage constructions were optimized by comparing different solutions for various details.

No time was left to build the tricycles, but the counterpart left the seminar with a complete set of technical drawings, so they could build the tricycle later. They actually did that.

The conclusion is that transfer of training applied to the following aspects:



A presentation of the basic loop in a design process. The bold blocks mark similarity between a children's tricycle and a tricycle for phisically impaired persons

Design process: identical. Techniques used for generation of ideas; discrimination of quality of solutions: identical.

Information gathering and analysis: with respect to the specific body dimensions identical, however different in terms of use and production.

DISCUSSION

During the six afternoons and two days, the designs of the children's tricycle were completed. The morning lectures proved helpful in understanding the construction of tricycles, but the application of theory to actual constructions appeared to be very difficult. The design process, together with the applied techniques, was found to be a helpful tool. It was agreed to use it during further execution of this project. It was concluded that:

- A new way of working was introduced to the counterparts. Their usual way of working is building a prototype directly in hardware and modify it until the result is satisfactorily. It was clearly demonstrated that by using a step by step approach, starting with sketches on paper with subsequent evaluations is a very efficient.
- Using data from simple ergonomic measurements is an effective way to determine the dimensions of a tricycle.
- Technological knowledge in local workshops is strong in producing complicated constructions with modest equipment. Theoretical knowledge is limited, resulting in poorly performing designs.
- Lots of knowledge is present locally in universities. This knowledge is difficult to come by for the counterparts as there is no tradition to exchange information.
- Ergonomic data is not readily available in workshops. It was taught that with relatively simple rules and measurements main dimensions of a tricycle can be obtained
- A manual should appeal to the technical knowledge present and give information in a pictural way rather then text and formulae
- The design process presented during this seminar was found to be a good tool for both designing and communicating.

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SIMPLIFIED STRENGTH TESTING OF MANUAL WHEELCHAIRS IN DEVELOPING COUNTRIES

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Abstract

Many small manufacturers of wheelchairs throughout the world's developing countries do not have the resources and technical background to test their products for safety and durability. This paper suggests some essential tests which they can easily perform. The tests are based on fifteen years of experience with the Whirlwind-type wheelchairs (which are manufactured and used in developing countries), and on the ANSI/RESNA Wheelchair Standards.

The paper is intended for use by manufacturers in developing countries who are working to improve wheelchair quality.

Background

There are many small to medium size wheelchair manufacturing shops throughout the developing world. In order to successfully market their chairs and serve their customers these manufacturers must provide chairs that are safe, durable, and good performers, and that are producible at affordable prices. This is an enormous challenge where money and materials are very limited. Although many wheelchair designer-mechanics demonstrate a high degree of skill and innovation in building chairs with available materials and tools, they often lack the background -- either educationally or experientially -- to evaluate their designs for safety and durability.

In recent years, standards for evaluating "Western" wheelchairs have been established. They are the ANSI/RESNA Wheelchair Standards (1,2) (in the U.S.) and ISO Wheelchair Standards (in Europe). These extensive Standards cover many subjects including: A uniform description of the basic seating dimensions of chairs so that consumers and health workers can accurately place orders; ways of determining tipping stability; minimal strength requirements to assure that the chair will not bend or break due to occasional high forces; and standard methods for testing long term durability where the chair is subjected to the equivalent of a lifetime of riding on rough surfaces and being dropped. There are several facilities in the United States and Europe equipped to perform the tests (3). Ideally, manufacturers in developing countries should submit sample chairs for testing at one of these facilities. However, the cost of transportation and testing is often prohibitive.

Problem Statement

Manufacturers in developing countries need simplified standards for testing their chairs. The testing methods, and minimum specified values, need to be appropriate for their testing capabilities, and their customers' riding environments. They need to include at least the tests essential to preventing catastrophic or serious functional failures.

Tests and Testing Method

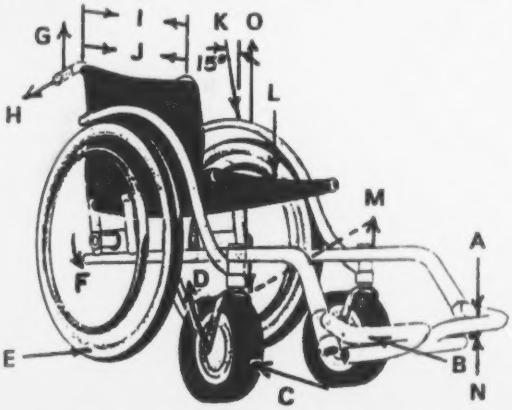
Fortunately, the following essential strength tests can be performed by manufacturers using simple equipment and procedures. However, the durability tests, and some of the impact tests, specified in the ANSI/RESNA Standards require complex machines that small manufacturers cannot afford. The issue of durability will be covered later under *Results* and *Discussion*.

The tests, testing methods and minimum values have been developed by Ralf Hotchkiss (see Acknowledgements), and others, during the more than fifteen years history of Whirlwind-type wheelchairs. They are based on mechanical analysis, laboratory testing to ANSI Standards, and extensive field testing by Ralf Hotchkiss and other riders. They found that a chair that passes these simple static or impact force tests is likely to pass the ANSI/RESNA tests. More importantly, it will also survive active use in rugged Third World riding conditions.

The diagram below shows the static and impact strength test forces a wheelchair of any design should withstand without breaking or sustaining permanent structural deformation. Tests which have been added to those in the ANSI/RESNA Standards, Part 8, or that have higher test values, are marked with an "*". The rest are similar, but not necessarily identical, to those in the

Standards. The related "Clauses" in the Standards are in brackets, [Cx.x]'s. A description of each test follows its minimum test value.

All the tests can be performed using a tape measure, spring scale, and a lever-arm made of strong pipe for measuring moments. For impact velocities, the tester can practice propelling the chair at 1.5 meters per second by, say, learning to traverse 12 meters in 8 seconds -- a fast walking speed.



The lettered arrows on the diagram show the direction and point of application on the test forces. A 91 Kg (200 lbm) active adult rider (either a dummy or willing person with a weight in their lap) is assumed.

To check for deformations, before-and-after test measurements should be made using the tape to measure the distance from:

- Rear wheel-to-rear wheel at the front and rear (toe-in or toe-out).
- Rear wheel-to-rear wheel at the top and bottom (camber).
- Caster axle to a rear-most point on the bottom of the each side frame
- Foot rest mounting points on the side frames to rearward points on the frames.
- Side-to-side between side frames at the foot rest mounting points, caster pivot bearing barrels, rear of bottom frame, and push handles, and between the front and rear of the seat tubes.

Test Values and Descriptions

A 1,000 N (225 lbf)[C6.3]-- Force of rider's leg pushing, or a "hitchhiker" standing, on Footrest.

B* 1,800 N (400 lbf)[C7.7]-- Impact force on one Footrest or front of chair running into a solid object, **or test by hitting a solid curb** at **1.5 m/sec (4.8 ft/sec)** -- a typical rolling speed.

C* 1,800 N (400 lbf)[C7.5]-- Peak force when one Caster Wheel with a soft rubber or pneumatic tire impacts a solid step, **or test as for B.** This tests both the caster fork and casterwheel.

D* 280 N-M (200 lbf-ft)-- Moment on a Caster Fork due to **C**.

E* 950 N (200 lbf)[C7.9]-- Force from wheelie off an 18 cm (7 in) curb, chair tipped sideways 10 deg., pneumatic tires on rear wheels.

F* 280 N-M (200 lbf-ft)-- Moment on Rear Axle due to **E**.

G* 1,140 N (250 lbf)[C6.8]-- Lifting force on Push Handle when pulling chair up stairs with one hand.

H 1,000 N (225 lbf)[C6.5]-- Pulling force on Handgrip during **G** - difficult to test. Use a good plastic-to-metal glue and skip testing.

I* 280 N-M (200 lbf-ft)-- Moment on Folding Mechanism or Frame Cross Members during **E**

J* 610 N (135 lbf)-- Pulling force of Seat Back fabric on top of Seat Back Tubes during **E**.

K* 1,140 N (250 lbf)[C6.2]-- Rider's hand force at an angle on armrest during pressure relief "push up", or boosting up to sit on the armrest to reach high.

L* 2,670 N (600 lbf)[C7.4]-- Distributed force along the seat during wheelie off curb in **E**.

M* 180 N-M (125 lbf-ft)-- Twisting moment on frame cross members when only two diagonal wheels are supporting the wheelchair on rough ground. Test with rider seated, tester holds one footrest down while lifting the opposite side-frame with force of **355 N (80 lbf)**.

N 440 N (100 lbf)-- Upward force on non-folding Footrest. Folding or removable Footrest must fold or remove at less than **44 N (10 lbf)** applied at the free end.

O 440 N (100 lbf)-- Upward force on Armrest. If the Armrest swings away or is removable, this must occur at less than **44 N (10 lbf)**.

Drop Test 40cm (16in), empty -- Impact during handling. Drop from the height on to each wheel when opened and folded.

Results of employing the tests

The current Whirlwind II design wheelchair passes these tests. One such chair was tested to, and passed, the ANSI/RESNA Standard tests, including the minimum 200,000 cycles on the double-drum durability tests [C8.2]. In addition, thousands of Whirlwind chairs have been built to established specifications, and are withstanding rigorous riding throughout the world. This attests to these tests being appropriate.

Therefore, passing the above static strength and impact tests is a good indicator of a chair's ability to also pass the ANSI/RESNA durability tests.

Discussion

It is recognized that passing the above strength and impact tests does not directly test fatigue failure of the structural materials or joints. For that reason it is recommended that chairs be built of materials that don't become brittle with repeated flexing.

For example, the Whirlwind chair uses malleable (mild or low-carbon) steel for the frame and other mechanical parts. This steel experiences minimal work-hardening when flexed well below its elastic stress limit. Also, when parts are inadvertently overloaded, they will bend rather than break -- avoiding a catastrophic safety hazard (16mm (5/8") diameter axle bolts, for example). Also, it is generally braze-welded (gas-welded with brass) because the steel at the joints has less tendency to become brittle, and a broken weld can be easily and reliably welded by local bicycle repairperson.

The Whirlwind chairs have the design features needed by a large segment of the wheelchair-riding public in developing counties. That is, they are designed for countries where the chairs will be used in both city and village environments where rough riding conditions exist. Also, the materials and techniques used to manufacture and repair the Whirlwinds are appropriate for these countries.

There are many good wheelchair designs, besides the Whirlwind, being manufactured. Also, shops trained to manufacture the Whirlwind often modify the design to meet requirements important to them or their customers. It is recommended that all current and future designs and modifications be strength and impact tested as suggested in this paper. Doing so should help improve the quality of wheelchairs so that they better meet the needs of riders, and keep good manufacturers in business.

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The information contained in this paper is primarily the results of tireless efforts and experience of Ralf Hotchkiss on behalf of people who need wheelchairs throughout the world. He is Technical Director of the Wheeled Mobility Center, SFSU, 1600 Holloway Ave., San Francisco, CA 94132, (415)338-7734.

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A PROPOSED LOW COST CUSHION DESIGN FOR INDIVIDUALS WITH SPINAL CORD INJURY IN DEVELOPING COUNTRIES

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Post International Seating Symposium Sore Butts Working Group

ABSTRACT

Two groups of interested individuals have met after the last two International Seating Symposiums (Vancouver'94, Pittsburgh'95) to brainstorm and create strategies for devices and educational efforts aimed at reducing the problem of pressure sores after spinal cord injury. This paper describes a prototype low cost cushion design, using commonly available materials, which may have some relevance for individuals with spinal cord injury in developing countries. This prototype effort relates directly to the Sore Butts Cushion Design Competition which is under development by RESNA's International Appropriate Technology Special Interest Group (SIG17).

BACKGROUND

Pressure relieving cushions have been used in the management of spinal cord injury for many years and are provided as part of the rehabilitation process routinely. They fall into broad catagories: contoured (standard shape or customized) which can be made of many different materials ranging from foam to cardboard; flat (normally foam or gel); air flotation; liquid flotation; gel; and combinations of the above.

STATEMENT OF THE PROBLEM

In developing countries spinal cord injuries are normally (80%) followed by death within 2 years as a result of pressure sore related problems, (1). Previous work related to low cost pressure measurement techniques (2) and vacuum consolidation (3) have attempted to address some aspects of the problem. Hotchkiss has developed a low cost cushion fabricated from layers of cardboard which is shaped by sitting pressures and carving to form a custom contoured cushion. His main problem with this is that the time it takes to manufacture a single cushion makes it an unattractive option. In Western countries mass production of cushions (and thus ready availability) is the standard approach with customization being reserved only for the most difficult problems, however most of these cushions vary in cost from $200-$400 dollars which is totally inappropriate for the target markets. As a price comparison, low cost devices which aid in the rehabilitation process, such as wheelchairs locally manufactured for about $150 are being successfully introduced in some countries (4).

RATIONALE

The International Appropriate Technology Special Interest Group (SIG17) within RESNA have for the past two years attempted to develop strategies which might address some of the issues related to pressure sore prevention. One of the strategies to emerge has been the development of the "Sore Butts Competition".

The purpose of this competition is to stimulate ideas for such devices that could be manufactured in the required locality, by the local population. It is envisaged that this competition will be run annually, resulting in evolving prototypes that will be of use in a variety of different settings.

This paper describes the development of a prototype low cost pressure relieving cushion for individuals with spinal cord injury, in order to provide insight into techniques which might reduce the incidence of pressure problems in this population. This prototyping experience helped in the development of the rules for the Sore Butts Competition.

DESIGN & DEVELOPMENT

Goals

The purpose of this work was to identify principles and techniques which may help to reduce the incidence of pressure sores amongst individuals with SCI in developing countries.

The group met in two sessions.

Session 1

Construction of prototypes and pressure measurement using the FSA Pressure Pad (5). Various combinations of the following devices and techniques were tested.

Inner tube frame	Air Flotn.
Chicken wire frame	Contoured
Towel	Flat
Beach ball- partially inflated	Air Flotn.

Wire frame Contoured

The conclusions of the group were that the most effective of these was the beach ball in combination with some contouring to provide additional support, in this case a towel folded to provide a pre-ischial bar. The following conclusions came out of further discussion and measurement and identified the basic ingredients of a proposed SCI survival kit.

-Beach ball	(cushion component)
-Towel	(cushion component)
-Balloon and tube	(pressure measurement(2))
-Bag	(calibration and container)
-Educational material	(how to be healthy)

Session 2

Discussion on the proposed SCI survival kit led to the following refinements.

Beach ball

This is one of the main cushion components and is a partially filled, non extensible air container. It is suggested that 2 would be provided, one in use and wrapped in pre-ischial bar as a spare, our tests used a 49" circumference beach ball.

Towel

This is the second major cushion component, size 27'X50", made from toweling, folded to 4 layers and rolled to form pre-ischial bar. The functions of the towel are to form pre-ischial bar for pelvic positioning and to cover over the beach ball to provide some cushioning in the event of accidental deflation.

Cushion Cover/Bag

This is the third major component. A simple cotton or similar material bag constructed with 2 draw strings, which enable it to fulfill three functions: a calibration function- to ensure approximately 4-5 US quarts Volume of air is in the beach ball; a container in which to ship/transport the kit; and a cushion cover, to cover the toweling pre-ischial bar and beach ball and maintain their position on the wheelchair.

Balloon and tube Pressure measurement

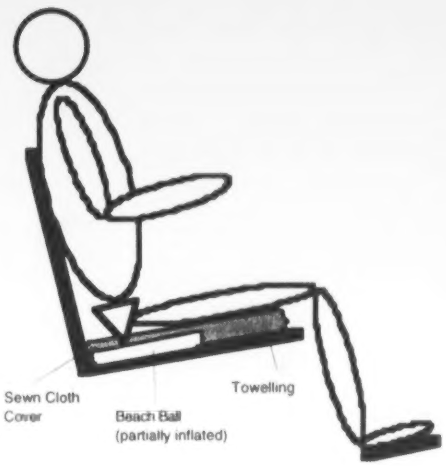
As previously defined and in current use (2) for ensuring safe sitting pressures.

Educational Material

This has still to be developed to provide individuals with guidance on how to stay healthy with a spinal cord injury, how to maintain cushion function and the purpose and process of carrying out sitting pressure measurement.

Vinyl repair kit

It is likely that any flexible air containing cushion will be damaged accidentally at some time. The vinyl repair kit will enable beach ball repair as necessary.



EVALUATION

Evaluation of the beach ball and pre-ischial bar toweling cushion was carried out using the Force Sensor Array (FSA) pressure measurement mat and was limited to one individual with a C6-7 spinal cord injury measured in the following configurations on the individuals regular Quickie 2 wheelchair.

Contour/gel cushion
Wheelchair Sling
Partially Inflated Beach ball
Partially Inflated Beach ball and Towel
Sling and Towel

Experience clinicians interpreted the data and concluded that, for this individual, the partially inflated beach ball and towel provided the lowest pressure readings.

It should be noted however that the disabled user felt unstable and would require additional lateral pelvic stabilization for longer term testing.

DISCUSSION

Surprisingly low pressures were achieved with a partially inflated (49" inflated circumference) beach ball based cushion. The pressure readout was very even. Casual observation indicated a "flat" ball, however 1 US gallon of air was the measured volumetric content of the beach ball, this allowed for a great deal of surplus beach ball material in the form of wrinkles which appeared to have prevented hammocking effects. Beach balls can be purchased by the dozen for about $10.00. With the cost of a towel, cover and other materials identified in Session 2 (above) it is likely that a cushion kit could be assembled for about $10.

Further evaluation work is necessary before a design can be finalized.

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ORTHOTICS, PROSTHETICS, AND ASSISTIVE TECHNOLOGY IN COCHABAMBA, BOLIVIA

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ABSTRACT

Assistive technology in Cochabamba, Bolivia is provided by private workshops and volunteers. The workshop of Carlos Guaman specializes in prosthetics and orthotics, but wheelchairs, crutches, and other devices are fabricated on request. Materials are difficult to acquire, components are custom fabricated, and most tools are made from scrap materials. Creativity and hard work leads to the creation of functional and durable devices.

BACKGROUND

Carlos Guaman.of Cochabamba, Bolivia has been trained in many areas of assistive technology through courses and experience in South America, Europe, and the United States. His educational background is in mechanical engineering and technology. The author, a mechanical engineering graduate student with experience in rehabilitation engineering, spent a month working in the workshop and in the Centro de Rehabilitacion Cochabamba (CERECO).

OBJECTIVE

The goal of the project was to learn about the methods of assistive technology service provision in Cochabamba, Bolivia.

METHOD

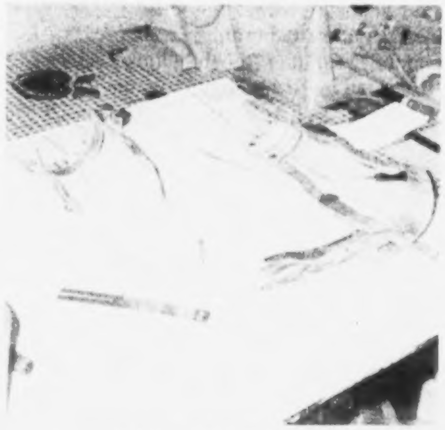
The first phase of the project involved observing and working with the physical therapists (PTs) at CERECO. The PTs were educated in two year programs similar to the physical therapy assistant programs found in the US Most of their equipment was donated by various humanitarian organizations. The majority of their patients were children with contractures, Down's Syndrome, cerebral palsy, and undiagnosed physical and mental disabilities. Most of the patients were able to walk with little or no assistance. Those that could not were carried. Wheelchairs were very rare, the majority of which were imported from the US and Europe and not very practical for the Bolivian terrain.

A typical therapy session included applying hot pads to the affected area, stretching, and strengthening exercises with ankle or wrist weights, a weight machine, and a stationary bicycle. Most patients had therapy a few times a week while some came every day.

Therapy session at CERECO

After working with some of the patients for several days, it was suggested that some could be assisted by splints and orthoses. Splints were made from splinting materials donated to CERECO. Hook and loop fastener for securing the splints was cut off of other equipment and sewn or glued to the splints.

Fabricating orthoses was a much longer process. One patient's knees hyperextended when he walked. In order to improve his gait, knee orthoses were designed to prevent the hyperextension. Tracings and measurements were taken of the patient's legs. Materials used in the orthoses came from items donated for the project and items in



Fabricating knee orthoses

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the workshop. Many of the parts were taken from used orthoses. The components that were not ready-made were fabricated from local materials, such as the leg bands that were made from aluminum automotive trim. As with the hand splints, much of the hook and loop fastener material was taken from other devices. The straps were made from several different locally produced fabrics. The original design, with metal leg bands, proved to be difficult to align, so the bands were replaced with polypropylene. In the process of realigning the orthoses for the new bands, some of the parts broke due to fatigue. Replacements could not be found so only one orthosis was completed.

Patient with knee orthosis

Ankle foot orthoses (AFOs) were requested for patients with disabilities including spina bifida, spasticity, and contractures. The process of making AFOs was similar to methods used in the United States, with modifications due to tools and materials. The patients' legs were cast to get a model for fabrication. Since no electric cast cutter was available, the cast was removed by cutting it with a knife made from a saw blade. A positive model was made by filling the cast with plaster. The positive model was finished using various tools, including files, screens, and hand-made scraping tools.

Polypropylene was not available so it was decided to laminate the AFOs using polyester resin. Latex condoms were placed over the plaster model as a separating media. For some projects, a compound of melted polyvinyl acetate (PVA) bags is used instead of condoms. Layers of stockinet, fiberglass, and various types of string were used as a strengthening matrix for the lamination.

In order to apply a vacuum, the model had to be contained within a PVA bag. In the United States, PVA bags are used only once and thrown away. Due to the difficulty in acquiring the material in Bolivia, the bags were reused several times and when they become unable to maintain a vacuum, they were melted and used as a separating medium. A vacuum machine that was donated to the workshop was used to achieve a vacuum. Prior to the donation, a vacuum was achieved by attaching a hose to the vacuum system of a car.

The polyester resin was mixed and colored with paint. It was poured into the PVA bag through a funnel made from a plastic bottle. Once the resin was hard the AFO was cut from the plaster with a hand saw and knife. A heat gun was used to heat and soften the laminate which was then cut with a knife. Once removed from the plaster, the edges of the AFO were finished with a donated router tool and hook and loop fastener was attached with glue.

Prostheses were made using many of the same tools and materials. The most difficult aspect of making prostheses was the componentry. Exoskeletal designs were preferred because they required fewer of the difficult to acquire prosthetic components, such as pylons.

Patient with above-knee prostheses

Sockets were laminated on plaster models of residual limbs. Thigh and shank portions were carved from balsa wood. If a section needed additional strength, blades from a hand saw were affixed to the wood. The workshop had one exoskeletal knee that had been donated. Whenever a knee was needed, the donated model was taken to the local foundry and a copy was made. A locking mechanism for the knee was made from local materials. The workshop had a few foreign-made SACH feet, but frequently feet were made from wood, leather, and tire rubber. Suspension systems were made from leather and other fabrics, sewn on a hand powered sewing machine.

Few upper extremity prostheses were made. Most terminal devices were made from local materials. One trans-humeral prosthesis was made from components donated specifically for a patient.

Other forms of assistive technology were made on request. Crutches were made from scrap metal and wood. Fabrics, plastics, and metals were used for wrist, knee, and neck braces. Special projects included a special leg orthosis to provide ischial weight bearing for a slow healing leg fracture.

A few wheelchairs were made by the workshop, on request. The fabrication process involved the use of many different facilities. For example, welding was done at a friend's workshop and the surface finish of parts was applied at an automobile factory. Due to the large amount of time and travel involved, the workshop has not gone into full-time wheelchair production.

RESULTS

At the end of the project, two hand-wrist splints, one ankle-foot sleeping splint, one knee orthosis, and five ankle-foot orthoses were completed. All devices were given to the patients free of charge. Over 150 pounds of prosthetic and orthotic devices were donated to the workshop.

Patient with ankle-foot sleeping splint

DISCUSSION

The work of rehabilitation providers in Cochabamba, Bolivia is an amazing study of caring and ingenuity. With very few materials and little compensation, physical therapists and assistive technology providers are able to aid many people. Educated in the most up to date methods of rehabilitation, they overcome the lack of equipment by creative use of appropriate technology.

ACKNOWLEDGMENTS

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CUSHION USING NATURAL MATERIALS -
A PRELIMINARY STUDY USING THE LEAVES OF THE YAU KAM CHI TREE

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ABSTRACT

The potential advantages of using natural materials for seat cushions were explored. Preliminary results using the leaves of the Yau Kam Chi Tree in home trials and in the laboratory were presented. Home trials by two able bodied volunteers were promising , especially in hot, humid weather, but inconclusive high pressure maps were obtained using the FSA. Simple material properties of the leaves were also presented.

BACKGROUND

Pressure sore is a common problem for the disabled world-wide. In affluent countries, expensive hi-tech ready-made cushions and custom contoured cushions have been used to minimize this problem. In developing countries, this is a serious problem pending appropriate technology solutions.

One successful example is a custom contoured cushion made with corrugated cardboard from discarded cardboard boxes used for packaging commercial goods. However, making a contoured cushion requires considerable skill and as the originator of the cardboard cushion pointed out, a supply of suitable cardboard boxes can not be taken for granted (1).

Using natural materials for bedding and cushions is not new. Human beings have been using fur from mammals, feather and down from birds, silk from silk-worms and cotton from the cotton-plant for such purposes throughout history. With the invention of modern materials such as polyester fibres and polyurethane foam, the use of natural materials has been decreasing. This decline is not only due to the desirable properties of man-made materials such as ease of use and hygiene but also due to the high cost of materials such as fur, silk and down.

In this city, where the summer months have temperatures around 30°C and humidity in the 90s, the leaves of the Yau Kam Chi tree have been used by some people as stuffing for summer-pillows. The dried leaves are still available in some bedding shops in older districts. The author spend about US$5 to made a pillow using the leaves and un-bleached cotton cloth. The pillow has a stiff, lumpy feel but is otherwise quite acceptable as a pillow, considering that the face is quite sensitive to irritation. One outstanding quality of the pillow is that it is not hot like a polyester or foam pillow (even with a cotton pillow case). It seems natural to try out the leaves for seat cushions. The Yau Kam Chi tree is often found in this city along country roads and in country parks. There is no known toxicity and the fruit from this tree is edible but not delicious (2,3).

RATIONALE

Essential and desirable cushion properties

Cushions for poor regions of the world must satisfy the following criteria:

1. *Acceptable pressure distribution:* Prolonged high pressure over a bony prominence is a major contributing factor of pressure sore formation. One of the major functions of a cushion is to keep the interfacial pressure within an acceptable level.
2. *Low cost:* With low financial resources, the cushions must be very low in cost to be affordable.
3. *Easy to produce:* With low financial resources, scarce capital is unlikely to be used in low demand special seating for the disabled. In addition, the disabled are most likely in the lower income bracket of rural society. Under these circumstances, special cushions are most likely either made by the users themselves or by people with limited skill.
4. *Easy to use and maintain:* Some hi-tech cushions requires pumping up air-sac compartments to appropriate pressures for good performance. Fluid filled cushions are subjected to puncture. Open cell foam cushions needs a good water-proof covering to prevent body fluid infiltration. All the above increases the difficulty in using and maintaining a cushion.
5. *Other considerations:* A lot of poor regions in world are hot and humid. Foam is a good insulator and trapped heat between the body and the cushion causes sweating. Shear stress is produced when a foam cushion deforms to conform to body shape. Sweating and shear are

contributing factors of tissue damage. Low shear and low heat built-up are desirable properties of a cushion, especially for use in hot and humid climate.

Tree leaves as a potential candidate

For low cost, the cushion material has to be available locally as well as of low commercial value. In this regard, materials with high commercial value, such as fur and silk may not be appropriate even if available locally. Tree leaves are good potential candidates because they are in abundant supply and usually has no commercial value. If a particular type of tree leave can be identified with acceptable pressure distribution property, the cost will be essentially nil if it is available locally in abundance and maintenance will also be minimal because soiled or spent leaves can be replenished freely.

Cushions made with loose leaves will likely not trap much heat like a foam cushion and shear stress may likely be low if the leaves are able to slide over each other. One perceived advantage of this type of cushion is that it can be fluffed and pre-shaped if desired before each use

Making a cushion out of leaves will be very simple. All that is required is to sew a cotton bag and stuff it with the dried leaves. Collecting and drying the leaves should not be a problem because time, space and sun are not usually in short supply especially in rural areas.

In rural areas, people commonly possess knowledge on local poisonous plants. Toxicity should not be a problem if any potentially suitable tree leave is checked against published data and local folklore.

Method and Approach

Two cushions were made with un-bleached cotton and stuffed with Yau Kam Chi tree (phyllanthus emblica L.) leaves. The cotton case was simply made by sewing two pieces of material together with a zipper on the back edge for convenience. The cushions were stuffed to a thickness of about 40mm. Two able bodied users, one being the author, would use the cushion from July to November, 1995 in the home without air-conditioning on and with the cushion on a flat wooden chair.

In early December, 1995, the cushions were taken back to our centre for pressure mapping with the FSA system calibrated for 200mmHg with the author as the single subject. The cushions were placed on a wheelchair fitted with a plywood seat.

Simple physical properties of the leaves from the cushions were measured for comparison with unused leaves. The following procedure was taken for leaves from each source:

1. 200ml of leaves was obtained by gradually putting leaves in a 400ml beaker and tapping on the side of the beaker until the 200ml mark was reached.
2. The beaker was taken to a material tester with a flat plastic disk of 74mm to provide about 1mm of clearance with respect to the internal diameter of the beaker. The disk was driven down at 6mm/min. The disk was stopped at pre-determined loads just long enough to manually take down the displacement reading.
3. The leaves were weighed.

OBSERVATIONS AND RESULTS

Qualitative evaluation

Cushion 1 was used by the author for an average of one hour per day mainly when using the computer at home while cushion 2 was used by a volunteer for an average of four hours a day while watching TV or reading. The author always sat on the cushion with both feet touching the floor. The other volunteer sat, kneeled and squatted on the cushion. Both users found that the cushions were firm but reasonably comfortable and can tolerate sitting on the cushion for about 1-1/2 hours a time. Both found perspiration, a common problem with foam and fibre filled cushions from experience, was not a problem in the area in contact with the leave cushion.

The author found that the cushion had some moulding property similar to that of a bean bag. An impression of the buttock remained after getting out of the cushion. Acceptable comfort was achieved not by sitting on a sat on cushion but by fluffing the cushion slightly and patting the cushion gently flat before each use. To prevent skin irritation, removing larger, stiff stalks of branchlets was desirable.

Appearance and densities of the leaves (Fig. 1)

Fresh leaves were a bit curly. The amount of flattening and breakage corresponded to the amount and style of use. The weight for 200ml of leaves were: unused (12gm), cushion 1 (18gm), cushion 2 (28 gm). Flattened and broken leaves packed better.

Pressure mapping with FSA (Fig. 2)

Cushion 1 and 2 both had a thickness of about 31mm. Relative to the flat plywood, the cushions did spread out loading. The amount of spreading decreased with the amount of use. The pressure under the ischia were high. For comparison, a 2" foam slab didn't

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give better results. Measurement using a single sensor of an Oxford Pressure Monitor showed a difference of about 100mmHg under the ischia when sitting on flat plywood and cushion 2.

Compression test (Table 1, Fig. 3)
A crackling noise, probably due to fibers breaking, was noticeable for the unused leaves and that from cushion 1 when the applied pressure exceeded 150mmHg. Downward displacement was taken relative to that at 10mmHg to allow for a bit of pre-compression. The leaves were compliant even at a pressure of 300mmHg. Compliance decreased with increasing pressure. The longer the leaves were used, the higher the decrease in compliance. Unused leaves had a much more uniform compliance.

DISCUSSION

The leave cushions are found to be acceptable by two able bodied volunteers, specially during hot humid weather. In contrast, inconclusive high pressures maps are obtained with the FSA. Evaluation by disabled subjects will be crucial but much care has to be exercised and volunteers may be difficult to find in this modern city. Interfacial pressure measurements using other techniques, such as the Dynamic Pressure Monitor or the Oxford Pressure Monitor will be useful to counter check the FSA results. A better protocol for pressure measurements has to be established. Simple material testing is done to characterise this loose aggregate material. But a better procedure, such as automatic data collection, has to be established especially for comparing different materials. Cyclic compression tests can be done in the laboratory to minimize the need for long term home trials.

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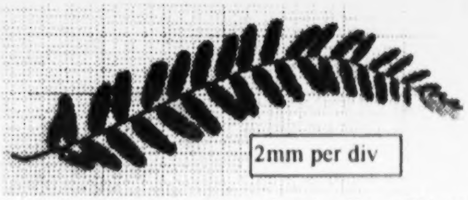

Fig. 1 A pressed branchlet of a Yau Kam Chi tree

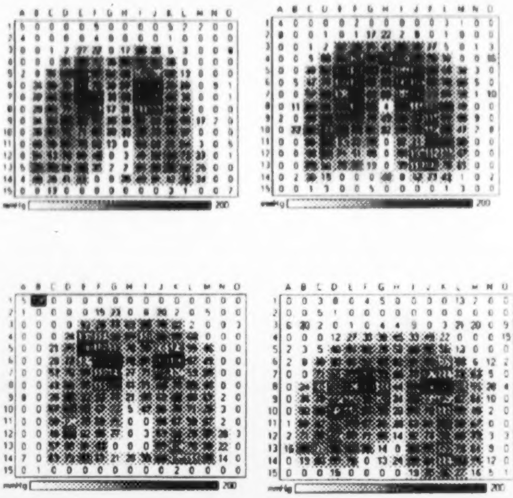

Fig. 2 FSA pressure maps (cw from top left)
a) flat ply wood seat b) cushion 1 (150hrs/5mths)
c) cushion 2 (600hrs/5mths) d) 2" foam slab

	Displacement (mm)		
mmHg	Cushion 1	Cushion 2	Unused
0	0	0	0
10	-3.3	-4.3	-7.7
50	-9.4	-9.8	-10.7
100	-13.4	-12.8	-13
150	-15.8	-14.6	-15
200	-17.6	-15.8	-16.6
250	-19	-16.8	-18.1
300	-20.2	-17.6	-19.5

Table 1 Compression test of leaves

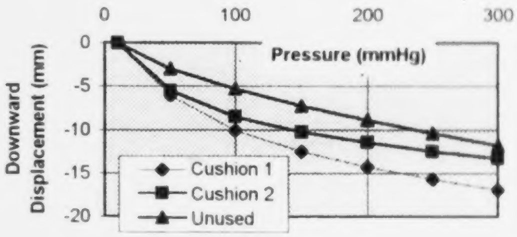

Fig. 3 Compression test of leaves

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NORTH CAROLINA'S ASSESSMENT OF ASSISTIVE TECHNOLOGY NEEDS FOR INFANTS, TODDLERS AND PRESCHOOLERS WITH DISABILITIES

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ABSTRACT

The Individuals with Disabilities Education Act now requires the provision of assistive technology devices and services to very young children. States often lack information needed to help them financially meet this mandate. A survey was conducted in November 1994 to assess assistive technology service and device needs of children ages birth to five enrolled in North Carolina's infant, toddler and preschool programs. Questionnaires were mailed to 539 agencies statewide. There were 160 responses (29.7%) providing detailed information on 2217 children currently receiving or needing assistive technology devices and services. Responses were received from a diverse sample based on sex, age, ethnicity, service setting and disability. Key findings are presented for costs of unmet equipment needs and current practices for assistive technology device and service provision. Recommendations are made for improved services to this population, including further study of observed trends based on ethnic differences.

BACKGROUND

In 1991, the provision of assistive technology devices and services was added to the Individuals with Disabilities Education Act (IDEA) in both Part H (Infant-Toddler) and Part B (Preschool) programs. According to IDEA, assistive technology devices include any piece of equipment or any supply or material that is purchased commercially, modified, customized or adapted which is used to increase, maintain or improve the functional capabilities of children. Assistive technology services assist in the selection and use of an assistive technology device and can include

- assessment of assistive technology needs and the functioning of a child in his natural setting;
- acquisition of assistive technology devices including purchase and leasing;
- choosing, adapting, repairing, maintaining and customizing assistive technology devices for children;
- coordination or use of services or therapies with assistive technology devices;
- provision of training and technical assistance for a child and his family; and
- provision of training and technical assistance for other service providers, professionals and other individuals who are significantly involved in the care and education of children with disabilities who need assistive technology devices.

Statewide needs assessment for assistive technology is relatively new. Most such assessments responded to passage of the Technology-Related Assistance Act of 1988, and have looked at assistive technology needs of all ages and populations (1, 2). Few studies have focused specifically on the technology needs of very young children across a state (3).

Since 1991, North Carolina has attempted to meet the requirements of IDEA including the provision of assistive technology devices and services. Federal and state Part H funds have been used to meet the assistive technology needs of children ages birth to five who are enrolled in the state's infant, toddler and preschool programs. This study's purpose was to assess assistive technology service and device needs of children, ages birth to five, with developmental delays, those experiencing atypical development and those at-risk for developmental disabilities. Information was also requested regarding monetary requirements for such devices and services to assist state officials in budgetary planning to meet those identified needs. Analysis of survey responses helps to indicate service/device delivery patterns and gaps for young children who have technology needs.

METHOD

In November 1994, a survey was conducted to assess the provision of, and need for, assistive technology for children from birth to age 5 in North Carolina. Using feedback from professionals and families, a survey questionnaire was developed that asked a series of questions for each child a program was serving. A grid-like format was used so that responses for multiple children could be entered on one page. Mail lists were obtained from as many programs as possible serving infants, toddlers and preschoolers with disabilities. Questionnaires were mailed to 539 agencies statewide.

RESULTS

Respondent Demographics

There were 160 responses (29.7%) providing detailed information on 2217 children currently receiving or needing assistive technology devices and services. Survey responses represented 62% male (N=1375) and 38% female children (N=841). All ages from birth through age 5 were represented: 15% birth to 1 year old (N=327); 16% 1 to 2 years old (N=357); 20% 2 to 3 years old (N=436); 21% 3 to 4 years old (N=457); 21% 4 to 5 years old (N=463); and 7% over age 5 (N=136). Caucasian children represented the largest ethnic group at 50% (N=1102) followed by African-American children at 32% (N=717). Hispanic children were the only other significant group at 4% (N=87). The next closest group was Native American children at 0.8% (N=18). The "Unknown" response was 11% (N=244). Respondents were from Early Intervention/ Developmental Day Programs (31%), followed by Public Schools (27%), Health Departments (17%), Developmental Evaluation Centers (8%), Head Start Programs (4%), Hospitals (3%) and United Cerebral Palsy Centers (2%). Children with developmental delay represented the largest number of respondents (N=656), followed by children with cerebral palsy (N=373), those at risk (N=342) and "other" (N=247). All 100 North Carolina counties had children represented.

Key Findings

The total cost of needed assistive technology devices for 839 children with disabilities birth to age 5 reporting (41% of respondents in this age group) is $2.49 million based on the dollar amount of all equipment a child is expected to need through age 5, including equipment ordered, equipment needed but not ordered or equipment expected to need. The average annual projected cost of needed assistive technology per child is $508 for children under age 1, $732 for children between 1 and 2, $952 for children between 2 and 3, $1788 for children between 3 and 4, and $3000 for children between the ages of 4 and 5. (Average annual projected cost was calculated by taking the total reported dollar amount needed per child from a given age through age 5 and then dividing by the number of years between their current age through age 5. For example, the average total cost of needed assistive technology per child under age 1 was $2540. Over a five year period the average annual projected cost is $2540/5 or $508. This, however, may not take into account increasing assistive technology needs in subsequent years.)

The average cost of needed assistive technology per African-American child ($2349, N=319) is one-third less than the average cost per Caucasian child ($3570, N=532). This may be due to differences in the prevalence of primary disorders reported for the various ethnic groups among survey respondents. In addition, significantly larger proportions of Caucasian children were reported to need seating and positioning equipment and computers, which can be high-cost items, whereas a larger proportion of African-American children were indicated to need "no equipment."

The assistive technology devices reported as most frequently recommended and provided for infants and toddlers are adapted toys, seating and positioning systems, learning aids and computers/computer access aids. The assistive technology devices reported as least frequently provided are aids for daily living and augmentative communication devices. The assistive technology devices reported as most needed by children birth through age 2 are learning aids, adapted toys and augmentative communication devices. For children ages 3 through 5, the most needed devices are augmentative communication devices, learning aids and computers/ computer access aids. The assistive technology devices reported as most needed by children with developmental delay are learning aids, augmentative communication devices and adapted toys. For children with cerebral palsy, the most needed devices are augmentative communication devices, seating and positioning systems and adapted toys.

For all children reported, approximately half (47%) of needed devices have been provided (55% for children birth through age 2; 42% for children ages 3 to 5). If an assistive technology device was not provided, the reasons most frequently reported are lack of funding (12%), that the device was ordered but not received (8%) and that there were no trained providers (8%). Other reasons included family decision, unclear recommendations, no follow through services and a large "other" response.

Medicaid was reported as the most frequently used funding source for assistive technology services. (Medicaid does not pay for most assistive technology devices for children in this age group. Medicaid does pay for many technology-related services, such as physical, occupational and speech therapies. It is likely that respondents interpreted this question to mean funding for assistive technology services, thus accounting for Medicaid's high proportion of responses.) The least frequently used funding sources are financial loans, civic/charity groups and nonprofits.

The most frequently provided assistive technology services are evaluation/assessment, child/family training and device selection. The least frequently provided services are device replacement, repair/maintenance, help with funding and customizing equipment. Children of this age group receive most assistive technology services in hospital/clinic settings (18%), Developmental Evaluation Centers (15%) and developmental day programs (14%). Most assistive technology services for infants and toddlers are provided by physical therapists, speech-language-pathologists, child services coordinators, special educators, physicians and occupational therapists.

DISCUSSION

A great deal of data were gathered as result of this effort. The results presented above represent a preliminary assessment of current practices and projected needs. Additional insight can be gained from more detailed review and analysis of the survey results. For example, further study is needed to understand differences in assistive technology needs of various ethnic groups. Based on these results, a larger proportion of African-American children were reported to be "Developmentally Delayed" than were Caucasian children, whereas significantly larger proportions of Caucasian children were reported to have "Cerebral Palsy" or to have "Orthopedic Impairments." It is critical to determine if identified trends in cost of needed technology are related to differences in disability prevalence (and thus different equipment needs) among these groups, or if they reflect differences in professional understanding and service delivery practices for children from various ethnic or cultural backgrounds. These differences in disabilities and types of equipment needed, if any, may account for the reported differences in average cost of needed devices among Caucasian and African-American children.

In addition, funding, as always, will remain a critical issue. The North Carolina Legislature currently appropriates approximately $1 million annually to meet the assistive technology needs of children with disabilities birth to age 5. Based on this survey's findings, an additional $1.5 million may be needed, with 28% of total equipment funds earmarked for children birth to age 3 and 72% of funding needed for 3 and 4 year olds. There will continue to be a need for providing training opportunities for public and private service providers, especially to increase the availability of follow-along services for families receiving equipment. We can also do a better job at increasing awareness of existing state funding for assistive technology devices and services for children birth to age 5. There is a need to expand funding options for children ages 3 to 5, and especially funding to purchase augmentative communication devices, learning aids and computers/computer access aids. And finally, a tracking system should be established for children identified in this survey to follow through on unmet needs.

It is our hope that future efforts to provide assistive technology devices and services to infants, toddlers and preschoolers with disabilities in North Carolina will both learn from and build upon the results of this needs assessment.

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SIG-19
Universal Access

THE UNIVERSAL TRAIL ASSESSMENT PROCESS

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ABSTRACT

One of the biggest obstacles the outdoors presents to people with disabilities is not a lack of access, but a lack of information. Existing trail grading systems and trail guides do not provide persons with mobility or visual limitations the information needed to determine if a trail can be hiked independently, with assistance, or not at all. The Universal Trail Assessment Process, developed by Beneficial Designs, collects objective information about the grade, cross slope, trail width, surface type, and magnitude of obstacles of individual recreation trails. The data collected during a Universal Trail Assessment can be used to create detailed trail guide products, such as pocket maps, trailhead signage and audio description tapes, that provide access, mapping and usage information about recreation trails. Outdoor enthusiasts can use this information to make decisions about which trails to use for recreational activities.

BACKGROUND

In 1990, the National Council on Disability held a public hearing addressing the need for improved access of parks and wilderness areas without excessive interference of nature. It was agreed that wheelchair users do not want to see the wilderness paved [1]. The Americans with Disabilities Act Accessibility Guidelines (ADAAG), passed in 1991, specify the accessibility standards for access to and inside public buildings. These regulations were never intended to apply to outdoor environments. The Access Board, who authored ADAAG, created the Recreation Access Advisory Committee to examine access to recreational facilities, including outdoor recreation access routes (ORARs) and recreation trails.

STATEMENT OF THE PROBLEM

The information conveyed in existing trail guides is largely subjective and contains little information about the conditions of a trail. A recreationist with a mobility or visual limitation does not have the information about the characteristics of a trail he or she needs to determine if it can be negotiated. An assessment process that collects objective information about the grade, cross slope, trail width, surface type, and magnitude of obstacles on a trail needs to be developed.

RATIONALE

The nutritional labels found on food packaging provide the consumer with objective information about the contents of the package. Armed with this information, the consumer can make his or her own decision whether or not to purchase the product based on his or her wants and needs. Similarly, the availability of objective information about the characteristics of recreation trails will allow all trail users to decide if a trail will satisfy their individual requirements. This type of information will benefit a wide range of trail user groups, including hikers, mountain bikers, snowmobile riders, horseback riders, ATV riders, children, older persons, and people with and without disabilities. People who enjoy outdoor environments also enjoy the physical challenge these outdoor environments represent and individuals with mobility and visual limitations are no exception. With the right information, all individuals can experience the pleasure of being in the outdoors without sacrificing the challenges of a natural environment.

DESIGN AND DEVELOPMENT

Four elements important when determining the level of access of a trail have been isolated: grade, cross slope, trail width and surface type. During a Universal Trail Assessment, trail assessment team members take these measurements at regular intervals along the trail, marked as stations. Additionally, notes are made about the magnitude of obstacles that are present in the trail. The trail assessment team is usually comprised of volunteers and consists of 3 to 12 members, including include a Trail Assessment Coordinator, a representative of the Land Management Agency, and a wheelchair user. Team members use easy-to-operate assessment tools when assessing a trail.

Trail Length/Distance to Key Points: The rolatape, a single wheel with an attached handle, is rolled down the center of the trail to measure the distance of the trail in feet. It is also used to measure the length of excessive grades and cross slopes, and the distance to points of interest.

Average Grade: Measurements of average grade are taken by two people working as partners. The partners face each other, one standing at one station and the other standing at the next, and sight to eye-level on their partner through a hand held device called a clinometer. The clinometer measures the grade between two stations. Average grade measurements are recorded in percent for that segment of trail.

Average Cross Slope: A digital inclinometer, with a length of 24 inches to reflect the approximate footprint of a standard wheelchair, is used to record the average cross slope. It is placed across the best portion of the trail at the station, left to right, (assuming a wheelchair user would choose the most level section of the trail for his or her path of travel). Cross slope measurements at each station are recorded in percent.

Maximum Cross Slope: Information about the maximum cross slope found on a trail is used to add detailed information to trail guides and trailhead signage. The team member operating the inclinometer stands at one station and determines visually if there is a change in cross slope to the next station (approximately 5% or greater). If so, the team member measures the values of the excessive cross slope by positioning the inclinometer across the trail width at several points along that portion of the trail. Because it is likely that the maximum cross slope will include a range of values, categories for maximum cross slope were developed (Table A). The category and/or range of values is recorded, as is the approximate length in feet the maximum cross slope occurs.

Maximum Grade: Like the maximum cross slope, information about the maximum grade found on a trail is used to add detailed information to trail guides and trailhead signage. The assessment team member operating the inclinometer stands at one station and determines visually if there is a change in the grade to the next station (approximately 5% or greater). If so, the team member measures the values of the excessive grade by positioning the inclinometer along the length of the trail at several points along that portion of the trail. Because it is likely that the maximum grade will include a range of values, categories for maximum grade were developed (Table A). The category and/or range of values is recorded, as is the approximate length in feet the maximum grade occurs.

Trail Bearing: The bearing of the trail is used to generate accurate trail maps. Working as partners, two people stand at consecutive stations, facing each other. Sighting through a hand held compass, each person determines the bearing to the station where his partner is standing.

Minimum Tread Width/Minimum Clearance Width: A tape measure is used to measure the width of the trail. The minimum tread width, or "beaten path," is measured at each station and is used to calculate the average tread width. Even if a tread width is narrower than the width of a wheelchair, a wheelchair user may be able to make use of the area to the outside of the tread width, provided he or she can safely roll over what comprises that area. Therefore, the minimum amount of usable passage space between stations, or minimum clearance width, is measured. This may or may not exceed the width of the "beaten path" and is used to calculate the minimum trail width.

Table A. Categories for Maximum Grade and Cross Slope

	%
Alpha	0-3
Bravo	3.1-5
Charlie	5.1-8
Delta	8.1-10
Echo	10.1-12
Foxtrot	12.1-14
Golf	14.1-16
Hotel	16.1-20
India	20.1-30
Juliet	over 30

Vertical Clearance: Obstacles such as low hanging tree limbs or outcroppings of rock can be vertical obstacles for many, including people with visual limitations. A device similar to a yardstick is used to measure obstacles that are lower than 120 inches from the ground on trails that allow horses and 80 inches from the ground on trails that do not allow horses.

Surface Characteristics: A judgment is made regarding the type of surface found in between stations. The type of surface is recorded, as well as a description of its characteristics (Table B).

Table B. Categories for Type of Surface

TYPE	FIRMNESS	SAMPLE
Paved	Firm, stable, slip-resistant	asphalt
Hard	Firm, stable, not necessarily slip-resistant	hard-packed aggregate, wood
Firm	Firm, not stable	packed dirt, gravel mix
Soft	Not firm or stable	soft dirt, bark chips, loose gravel
Very Soft	Not firm or stable	fine sand, pea gravel

Magnitude of Obstacles: According to the ANSI/RESNA Wheelchair Standards, 28 inches is the maximum overall width recommended for a wheelchair. Therefore, the magnitude of obstacles protruding into a 28-inch trail width is measured. The width and length of obstacles are measured with a tape measure. A height recorder is used to measure the height of obstacles. This device is comprised of a tape measure attached to a plastic rod with one end of the rod fitted into a base. The base is set firmly on the ground next to the obstacle. An adjustable T-bar is designed to slide up or down the rod until it rests on the highest portion of an obstacle.

Data Collection: Data collection is usually done by hand on a Trail Data Form. The data collection fields in a GPS unit can be programmed to record data and the GPS unit itself records the bearing of the trail. However, most units are not accurate enough in the Z axis to eliminate the need for using clinometer readings to get average grade.

EVALUATION

Initially, 10 recreation trails in Yellowstone National Park and the Gallatin National Forest were assessed using the Universal Trail Assessment Process. Trail guide products including pocket maps, trailhead signage and audio description tapes were generated with the data collected. Two of the trails, Fairy Falls and Ice Lake, were reassessed after two years. Measurements from the second assessment were consistent with the first, demonstrating the repeatability of the process. Trailhead signage, pocket maps and audio description tapes were generated for Grotto Falls Trail and Palisade Falls Trail. Volunteers, including 15 individuals with mobility limitations and 15 with visual limitations, were asked to use one or more of these products and provide feedback about the content and layout of each. Revisions were made based on the feedback received.

In 1995, over 65 people from several national, state, local and private agencies and organizations were trained as Universal Trail Assessment Coordinators. These individuals, who included representatives from the USDA Forest Service, the USDI Park Service, the Bureau of Land Management, the Bureau of Reclamation, US Fish & Wildlife, and the National Center on Accessibility, participated and led several trail assessments during the training workshops. They were asked to provide feedback based on their experience, and their comments were used to fine tune the assessment process, training materials and workshop curriculum. These trainees are conducting trail assessments in their own regions using the Universal Trail Assessment Process and will send their data back to Beneficial Designs where trailhead signage and mapping artwork will be generated. Several of these trails will be re-assessed by Beneficial Designs to determine the repeatability of the assessment process when conducted by individuals other than Beneficial Designs staff.

DISCUSSION

Parks and Forests struggle daily with the issue of what kind of trail information is important, how they can collect this information, and how they can present it to their visitors. The Universal Trail Assessment Process provides a way to collect necessary access information. Furthermore, in these days of budget and staff cuts, a trail assessment team using the Universal Trail Assessment Process has the tools necessary for conducting a complete trail inventory and can collect information about trail usage and maintenance needed, as well as access information. Agencies with trained trail assessment coordinators find that volunteers enjoy participating as Universal Trail Assessment team members.

Beneficial Designs is developing the standard format for Universal Access Information for use by all agencies. Additionally, a software module is being created so that others will have the ability to process their trail data in-house and generate Universal Access Information to meet their needs. The overall goal of this project is to use the Universal Trail Assessment Process to collect objective information about recreation trails and to generate trail guide products that convey this information to different trail user groups, including hikers, mountain bikers, snowmobile riders, horseback riders, ATV riders, children, older persons, and people with and without disabilities. Everyone has different needs, but with Universal Access Information all trail users have the information they need to make decisions about which trails to use. The intent of this project is to make the availability of detailed access information the norm, rather than the exception.

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DEVELOPMENT AND VALIDATION OF PRINCIPLES OF UNIVERSAL DESIGN

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ABSTRACT

The authors are involved in a collaborative effort to establish and validate universal design principles to guide a wide range of design disciplines including environments, products, and communications. Presented here are seven universal design principles useful for evaluating existing designs, guiding the design process, and educating both designers and consumers about the characteristics of more usable products and environments. Applications of these principles hold promise not only for improving the usefulness of commercial products for people with disabilities but also for broadening the market for assistive technology.

BACKGROUND

In our society, mass production and broad marketing have been used to reduce costs for consumers and generate profits for manufacturers. Because the market for products for disabled and older people is generally perceived as small and specialized, the advantages of mass production and marketing have not been realized. Specialized products and spaces designed only for people with disabilities and older people will always be more expensive, look different, and carry a certain stigma. Rather than continue to produce special and expensive products and environments, why not adopt a more "universal" design approach to the design of all products and environments?

Since the 1980s, a small but dedicated group of designers and advocates has been promoting the concept of universal design as a way to create products and environments that are more usable by everyone, regardless of age or disability. Universal design is a concept intended to increase the market for and, thus, production of products and environments that are usable by everyone to the greatest extent possible (Mace, 1985). By making more products and environments usable by more people, both the need for and higher cost of specialized products and environments is reduced (Mueller, 1990). And given the choice, all consumers are likely to prefer more usable products and environments.

Terms such as accessible, adaptable, barrier free, transgenerational, life span, and universal design have been used almost interchangeably. It is important, however, to distinguish universal design from other approaches used to achieve accessibility in products and environments. Universal design is a different approach with distinct advantages.

Accessible design refers to the design of specialized products, buildings, and exterior spaces to meet the needs of a selected segment of the total user population. Building code accessibility requirements are a good example of this approach. The distinguishing characteristic of accessible designs is that they typically are different from "normal" designs and, therefore, may contribute to segregation and stigma (e.g., handicapped entrance, seating, bathroom, etc.). Moreover, because they are different and often duplicative, these design solutions also tend to be more expensive.

Adaptable design refers to the design of certain products and environments to include features that can be readily adapted to the needs of particular users. A good example of adaptable design is the Braille overlays that some manufacturers provide for their appliances that can be used to make the display and controls legible to a person who is blind. The distinguishing characteristic of adaptable design solutions is that the existing product or environment must be adapted, adjusted, or added onto in order to make it more usable.

Universal Design can be defined as the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design. While few products or environments are truly usable by everyone, certain designs are more usable that others in identifiable ways. Lever door handles, for example, are generally easier for more people to operate than are traditional door knobs; an automatic door opener is usable by anyone able to approach a doorway, making it a more universal solution.

The important characteristics of universal design solutions are that nothing needs to be added or adapted to make the product or environment more usable, these solutions do not segregate users, and in making the product or environment more usable by people with disabilities it does not become less usable by those who are not disabled. This last point is important because universal design approaches should be preferred by all users and, therefore, more widely marketable than existing designs.

Many products such as environmental controls and cordless telephones are useful both to people with and without disabilities. Similarly, many assistive technologies could have wider application than is currently being exploited. Certainly ramps are used as readily by people using strollers or moving furniture as by people using wheelchairs. Public telephones with volume control handsets assist people with hearing limitations but are also beneficial to anyone in a noisy environment. Expanding the market for assistive technology into commercial markets could help reduce the cost and stigma often associated with assistive technology.

STATEMENT OF THE PROBLEM

The universal design concept lacks established criteria to determine what makes for a more usable product or environment. Designers presently have only accessibility building codes and standards and limited human factors data to rely upon. At best, these sources provide minimum requirements or guidelines, which fall substantially short of ideal. To date, universal design has been described largely through example -- recognition of good designs that illustrate the concept. Guiding principles and specific design criteria are needed so designers have a clear understanding of what is meant by the concept, when it should be applied, and how to accomplish it.

Universal design principles should guide the design process and provide a benchmark against which to compare new designs for their universal usability. Providing the designer with universal design principles and criteria by which to evaluate his or her design would encourage a variety of design solutions rather than dictating one accessible solution to a given problem.

APPROACH

The authors are involved in a collaborative effort to establish and validate universal design principles to guide a wide range of design disciplines including environments, products, and communications. A working group of architects, product designers, and environmental design researchers has identified seven universal design principles for use in evaluating existing designs, guiding the design process, and educating both designers and consumers about the characteristics of more usable products and environments. The seven principles are presented here, in the following format: *name* of the principle, intended to be a concise and easily remembered statement of the key concept embodied in the principle; *definition* of the principle, a brief description of the principle's primary directive for design; and *guidelines*, a list of the key elements that should be present in a design which adheres to the principle. (Note: all guidelines may not be relevant to all designs.)

PRINCIPLE ONE: Equitable Use

The design is useful and marketable to any group of users.

Guidelines:

1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.

1b. Avoid segregating or stigmatizing any users.

1c. Provisions for privacy, security, and safety should be equally available to all users.

PRINCIPLE TWO: Flexibility in Use

The design accommodates a wide range of individual preferences and abilities.

Guidelines:

2a. Provide choice in methods of use.

2b. Accommodate right- or left-handed access and use.

2c. Facilitate the user's accuracy and precision.

2d. Provide adaptability to the user's pace.

PRINCIPLE THREE: Simple and Intuitive Use

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Guidelines:

3a. Eliminate unnecessary complexity.

3b. Be consistent with user expectations and intuition.

3c. Accommodate a wide range of literacy and language skills.

3d. Arrange information consistent with its importance.

3e. Provide effective prompting for sequential actions.

3f. Provide timely feedback during and after task completion.

PRINCIPLE FOUR: Perceptible Information

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Guidelines:

4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.

4b. Provide adequate contrast between essential information and its surroundings.

4c. Maximize "legibility" of essential information in all sensory modalities.

4d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).

4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

PRINCIPLE FIVE: Tolerance for Error

The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Guidelines:

5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.
5b. Provide warnings of hazards and errors.
5c. Provide fail safe features.
5d. Discourage unconscious action in tasks that require vigilance.

PRINCIPLE SIX: Low Physical Effort

The design can be used efficiently and comfortably and with a minimum of fatigue.

Guidelines:

6a. Allow user to maintain a neutral body position.
6b. Use reasonable operating forces.
6c. Minimize repetitive actions.
6d. Minimize sustained physical effort.

PRINCIPLE SEVEN: Size and Space for Approach and Use

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Guidelines:

7a. Provide a clear line of sight to important elements for any seated or standing user.
7b. Make reach to all components comfortable for any seated or standing user.
7c. Accommodate variations in hand and grip size.
7d. Provide adequate space for the use of assistive devices or personal assistance.

IMPLICATIONS

As noted, the principles of universal design are intended to assist in the evaluation of products, environments and communications, and to educate designers and consumers. To that end, work is currently underway to establish the validity of the principles in these applications.

The development and promulgation of principles of universal design has several implications for the design of assistive technology. Their presentation to RESNA is intended to prompt discussion concerning at least three:

1. To what extent can the need for assistive technology be reduced by making all products and environments more universally usable?

2. How can these principles be used to promote compatibility with and, therefore, facilitate use of assistive technology?

3. How can the market demand for assistive technology be increased by incorporating universal design features to broaden its applicability and appeal?

DISCUSSION

It must be acknowledged that the principles of universal design in no way comprise all criteria for good design, only universally usable design. Certainly, other factors are important, such as aesthetics cost, safety, gender and cultural appropriateness, and these aspects should be taken into consideration as well when designing. Whenever possible, however, attempting to broaden the market beyond strictly people with disabilities or those who are older will increase the size of the market. It can reduce the cost of the product, and reduce the segregation and stigma that may be associated with it.

The universal design principles and related guidelines can provide an important starting point but by no means a complete solution to creating a more universally usable world. Adherence to these principles does not replace the need to involve consumers in the design process to the greatest extent possible. By the same token, encouraging designers to embrace a more empathic approach and view their work from the perspective of the full range of prospective users is an important step in the right direction.

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ACCESSIBILITY GUIDELINES FOR ELECTRONIC KIOSKS

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Abstract

Accessibility to electronic kiosks such as ATMs, information kiosks, and directories is an important aspect of the spirit of the ADA Guidelines. With the advent of the quick information retrieval systems which are designed to be used by the general public, the need for universal accessibility guidelines has arisen. Although computer interaction is the impetus for these guidelines, it is important to note that the guidelines apply only for short term use of computers as when utilizing a kiosk.

Background

The research team was approached by the Atlanta Paralympic Organizing Committee to design an accessible kiosk for the 1996 Paralympic Games. It was imperative that the kiosk be accessible to a vast array of users, as there would be a large contingency of wheelchair users present at the games. As many as 200 of these kiosks will be present throughout the venues.

The kiosk would present, upon request by the user, information on venue location, event scheduling and event results in a touch-screen format. The following text and illustrations are the results of the research completed to meet the goals of the project. This research provided the necessary height, depth and angle guidelines for the completion of the project and is applicable in similar electronic equipment interfaces.

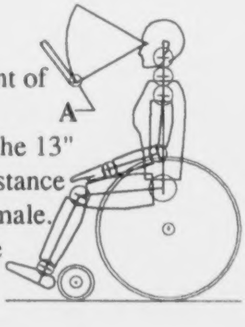
Objective

The guidelines for kiosk design should offer specific dimensions which allow for the greatest degree of accessibility to 95% of the population. The guidelines should apply to any kiosk-type device utilizing a touch-screen or a flat mounted keypad/monitor combination. The guidelines should be in concordance with current ADA standards.

Approach

The user group specified for these guidelines encompasses a range from a 58" female wheelchair user to a standing 74" male. The 58" female represents the 2.5% United States female and the 74" male represents the 97.5% United States male. The approach used is a six step process of placing different human models in relation to a monitor and adjusting the monitor height, angle and kneewell depth according to the extremes of the appropriate model. The process is illustrated with the accompanying figures. All reach and eye-gaze dimensions are found in Humanscale 1/2/3.

Figure 1.



Point A, the closest point of the monitor to the user, must be no closer than the 13" comfortable viewing distance arc of the seated 58" female. The points represent the actual screen extremes.

Figure 2.

Point **A** is confirmed by the intersection of the standing 74" male's comfortable 27.5" reach arc with the sight arc of the seated female from Figure 1.

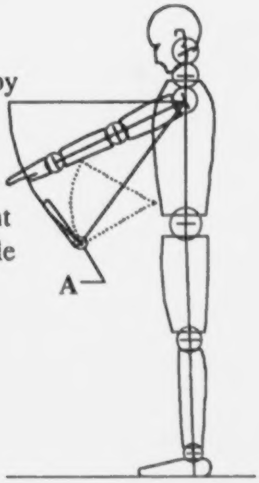


Figure 3.

Point **B**, the top of monitor, is found along the 21.5" comfortable reach arc of the seated 58" female. The model is in the same relative position to Point A as she was in Figure 1.

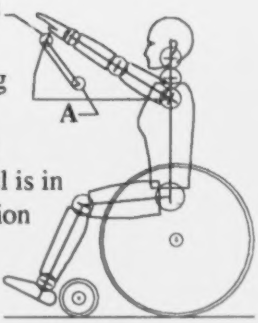


Figure 4.

Angle **C**, the angle of the monitor from horizontal, is determined by a compromise between the sight lines of the standing male and the seated female from a line perpendicular to the screen. This angle accounts for a comfortable head-tilt and eye-gaze for both.

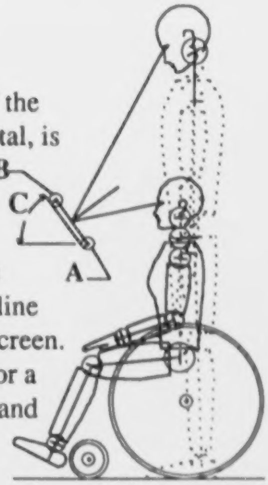


Figure 5.

Distance **D**, the minimum distance from Point A to the closest foot interference, is found by placing a seated 74" male at a comfortable 27.5" reach from Point B.

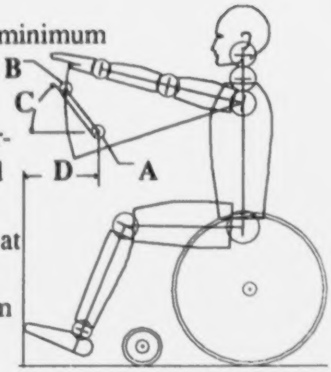
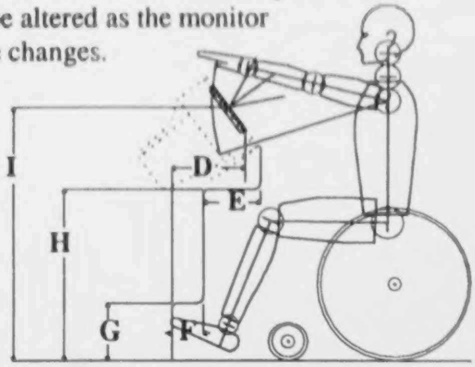


Figure 6.

Distances **E, F, G** and **H** are all found by incorporating ADA 4.24, lavatory knee and foot clearance, into the design and are not to be altered as the monitor size changes.



Distance **E**: Distance from front of structure (NOT monitor screen) to knee obstruction must be greater than 8".
Distance **F**: Distance from foot obstruction to leg obstruction must be less than 9".
Distance **E + F** must be greater than 17".
Height **G**: Height from floor to toe obstruction must be greater than 9".
Height **H**: Height from floor to upper leg obstruction must be greater than 27"
Height **I**: Height from floor to centerpoint of monitor screen is disclosed in steps 1 - 5.
Note: Clearance width for forward approach to kiosk must be 30" or greater.

Results

The preceding six step method was applied to 7", 10", 12", 15", 17", and 20" monitors for the study. This method provided optimum monitor heights and angles for each size tested. The accompanying statistics illustrate the results and must be utilized if 95% accessibility is to be realized. Please refer to Figure 4. for the location of Angle C. Refer to Figure 6. for the locations of Dimensions D and I.

Monitor Size	C°	Dmin.	I
7"	68°	9"	44.5"
10"	60.5°	9.75"	42.25"
12"	56.5°	10.5"	41"
15"	53°	11.5"	40"
17"	44.5°	13.5"	37"
20"	35.5°	16.25"	35.5"

It should be noted that these figures show the results for the monitor screen itself and not the actual monitor housing.

On the 17" and 20" monitors, this method will only work with a very shallow depth monitor, such as an LCD flat-screen, as the monitor housing would interfere with the kneewell. Using readily available monitors, a 15" diagonal monitor is the largest feasible size. If, however, the kiosk is designed to utilize a LCD monitor or a thin keypad, any of these sizes will work.

Discussion

The preceding method for creating these dimensional guidelines was ultimately used for the Paralympic Kiosk. The kiosk utilized a 15" touch-screen monitor at 53° tilt from horizontal. There was a 27.75" floor to knee clearance and a 30" clearance width for approach. The first prototype was tested successfully by several wheelchair users, a 99% male and by several persons of short stature. The kiosks are currently in production and are awaiting use at the 1996 Paralympic Games in Atlanta.

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THE STANDARDS PROCESS AS A ROUTE TO UNIVERSAL DESIGN IN TELECOMMUNICATIONS: THE CASE OF V.18

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ABSTRACT

One approach to universal design is the incorporation of assistive technologies into the design of products sold to the general market. To achieve this type of accessible design feature in general products, the development of industry standards can be helpful.

This paper presents a case of standards development in the area of text telephony. In September, 1994, the International Telecommunications Union's Telecommunications Standardization Sector (ITU-T, formerly CCITT) approved Recommendation V.18,[1] which specifies an interworking protocol between conventional computer modems and text telephones. Once implemented, V.18 will result in text telephone capacity in conventional modems. This capacity will greatly increase the opportunity for direct text telecommunication among deaf and hearing people, and will provide compatibility with text telephones of other countries. V.18 represents the fulfillment of a partnership among industry, researchers, and consumers.

BACKGROUND

People who are deaf use text-based methods of telephone conversation. The first device to gain widespread use by the deaf community was an adaptation of the teletypewriter, or TTY. The TTY network began in 1964 when Robert Weitbrecht, a deaf physicist, developed an acoustic coupler for transmitting over the telephone network the Baudot code used in teletype transmission. The TTY network gave deaf people significant relief from the barrier created by the voice telephone.

While the TTY network was growing in the deaf community, personal computers entered the market. The computer modem became a common component of computer workstations, as the emergence of bulletin boards, on-line services, and the Internet created useful applications for modems.

On the surface, it appeared that computer modems using ASCII protocols should replace Baudot TTYs, which represent a technological backwater. However, the situation is not so clear-cut. Baudot, although slow and implemented in half duplex, has a number of advantages over ASCII protocols for telephone conversation. Advantages include instantaneous connection and a carrierless mode that is tolerant of the voice environment, whereas ASCII protocols used in American TTYs disconnect upon significant disruption to the carrier.[2] The embedded base of Baudot TTYs is quite large, numbering in the hundreds of thousands. Despite the growing availability of ASCII, deaf people have continued to use Baudot. Even today, no more than 5% of text telephone calls to telephone relay services are initiated in ASCII.[3]

OBJECTIVE

Based on these factors, and based on the telecommunications industry's principle of accommodating the embedded base as technology evolves, an effort was begun to foster migration to ASCII without forcing consumers to abandon Baudot.

METHODS

Gallaudet University began by contacting the Telecommunication Industries Association (TIA) for assistance. TIA recommended Richard P. Brandt, chairman of the domestic TR-30 committee on modems and vice chairman of Study Group XIV of the ITU-T (formerly CCITT) on modems. The initial goal was to work with the domestic TTY industry to correct some difficulties with ASCII implementation in U.S. TTYs.

Gallaudet, in cooperation with the consumer group Telecommunications for the Deaf, Inc. (TDI), began hosting industry meetings at conventions of consumer associations. The process was handled outside any formal standards body, an earlier attempt by the Electronic Industries Association to standardize TTYs had failed, and the requirements of a formal process were impossible for us to satisfy. Included in the discussions were all domestic TTY manufacturers, manufacturers of TTY-accessible call-handling equipment for 911 centers, and companies operating telephone relay services. Considerable progress was made with identifying how ASCII should be implemented in American TTYs, but it was unclear whether industry would implement these recommendations. As stated previously, the ASCII feature in TTYs is not widely used by deaf people, and the market did not seem to justify re-engineering.

Brandt quickly recognized that the problem was, in fact, an international problem. Telecommunications standards are international standards, since they require connectivity among devices and networks from all countries.

Brandt initiated standards development by petitioning the U.S. Department of State. ITU-T Study Group XIV subsequently undertook the development of an interworking protocol between American text telephones and computer modems. Very soon the study was broadened to include text telephones from European countries. Several European countries had developed their own approaches to specialized text telephones in the late 1970s and early 1980s. In all, six different text telephone protocols--all incompatible with one another--are in operation in Europe.[4] This situation poses a dilemma to those concerned with organizing a single European Union. Work on V.18 was eventually embraced by these countries as one possible route to a solution.

The development of the standard was an international collaborative process of researchers, computer scientists, standards experts, and consumers. Much of the collaboration was made possible by the Internet, which removed barriers of space, time, and disability. The document was revised many times between its initiation in 1992 and its adoption in 1994.

The involvement of technically knowledgeable American consumers, particularly Norman Williams of Gallaudet, was critically important to the process. U.S. deaf consumers and TTY manufacturers were kept informed via regular articles in consumer newsletters. Manufacturers also received all revisions to the standard, and continued to meet yearly for purposes of giving input, until V.18 was completed.

RESULTS

As noted above, the ITU-T approved V.18 in September of 1994. The key provisions are these:[5]

- a calling tone, which will speed the connection process and alert hearing people and automatic detectors to an incoming text telephone call;
- prohibition of automatic disconnect, so that the caller has full control over call completion and disturbances caused by voice and call transfers will not terminate the call;
- re-connection after loss of carrier, a feature required for situations in which calls are transferred;
- a method of displaying line energy, to give the user a way to interpret line status by watching the display;
- conversion of codes used in text telephones internationally, including Baudot, Bell 103, DTMF, EDT, V.21, and V.23;
- interworking specifications and flowcharts.

DISCUSSION

These observations may prove helpful to others seeking to employ the standards process to achieve improvements in universal design and compatibility with assistive technologies.

An international standard has the following advantages:

- Dissemination of information to a large international industry is handled by industry's own channels. A wide variety of companies, from Hayes to Microsoft, were aware of V.18 without outreach from those involved in standards development.
- Manufacturers from around the world have the opportunity to participate in standards development; much free technical assistance is provided during the development phases.
- The standard may, at some future date, be incorporated into mandatory government standards. If this happens in Europe, the worldwide implementation of V.18 in commercial products will be assured.
- The problem of incompatibility among the world's text telephones can be addressed.

The standards process has, of course, this important limitation: Adoption of the standard is entirely voluntary unless a government requires it of the industry. This rarely happens in the U.S. Although the word "standard" gives the impression that universal design is assured, this is not at all the case.

By seeking the solution to a domestic problem, we ended up with a possible solution to both a domestic and an international problem. The project also paved the way for future telecommunications standards aimed at universal access. Once the standard was written, it became part of the culture of the standards groups, and greatly raised their awareness.

As is often the case in universal access efforts, the key to success was the interest and dedication of someone from the industry side willing to be a champion for the effort. Dick Brandt contributed most of the time spent working on V.18, and was fully dedicated to the project from beginning to end.

Funding was contributed from multiple sources. Government funding permitted researchers to be involved and contribute to the standard. Industry supported travel and Brandt's later work on V.18. Government grants are not generous enough to finance the kind of commitment in terms of travel and time that is required, and this could hamper future efforts unless industry stays involved.

CONCLUSION

The ultimate realization of the goal will be a widely adopted standard and effective products. More than a year has passed since V.18 was approved, and to date (December, 1995) there is no product on the market. Recently British Telecom has revealed development of a V.18 prototype; it is hoped this will lead to commercialization. As always, uncontrollable business decisions dictate the success or failure of any attempt at universal design.

It is hoped that V.18 products will take many forms, from modem cards to conventional TTYs. There is still a market for free-standing equipment in businesses and homes, and the assistive technology companies can still thrive by producing these devices.

The next challenge will be testing of prototypes and early products, in concert with deaf people in other countries, to ensure that V.18 serves the consumer as an effective TTY. Additional standards work will be needed to address the issue of character sets and other issues pertaining to international communications.

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DESIGN SPECIFICATIONS FOR OUTDOOR RECREATION ACCESS ROUTES AND RECREATION TRAILS – A PILOT STUDY

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ABSTRACT

Design standards for outdoor recreation access routes (ORARs) and recreation trails have been proposed by the Access Board. These include specifications for grade, cross slope, and change in level for four degrees of access. The purpose of this pilot study was to determine if the grade and cross slope specifications for each degree of access category (easier, moderate, difficult, most difficult) matched the perceived level of difficulty. Twelve subjects representing a spectrum of physical abilities completed five performance tests to assess physical fitness and skill, performed maximum grade and cross slope tests, subjectively rated the level of difficulty of 36 different grade/cross slope combinations, and subjectively rated four ORARs/trails. In summary, subjects were capable of negotiating much steeper grades and cross slopes than previously expected, indicating that the proposed design standards are too strict. Based upon the results of this research and numerous trail assessments, new design specifications have been recommended. These results support the need for further research to re-evaluate the design specifications for ORARs and trails.

BACKGROUND

Current ADA Accessibility Guidelines address access to and in buildings and facilities in highly developed areas. Access to outdoor environments is equally important to people of all abilities who desire to participate in recreation and leisure activities. For this reason, the Access Board (US ATBCB) created a Recreation Access Advisory Committee and charged them with developing recommendations for accessibility guidelines for recreational facilities and outdoor developed areas. These recommendations included design standards for outdoor recreation access routes (ORARs) and recreation trails. The results of 10 Universal Trail Assessments which included objective measurements of grade, cross slope, width and obstacle height were closely examined [1,2,3]. Using this information, the committee developed specific requirements for grade, cross slope, width and small level changes for three degrees of access: easier, moderate, and difficult. ORARs and trails exceeding the difficult category were considered "Most Difficult."

In July of 1994, the Advisory Committee submitted a report to the Access Board which contained the written recommendations [4]. Due to the time constraints set forth by the Access Board, it was unfeasible for the committee to conduct research to validate all of the standards proposed for ORARs and recreation trails.

1994 Proposed Designs Standards for Outdoor Recreation Access Routes

	Easier	Moderate	Difficult
ave. grade	5 %	5 %	8 %
max. grade	8 %	10 %	10 %
for a distance of	30 ft	50 ft	50 ft
max. cross slope	3 %	3 %	3 %
max. level change	1/2 in	1/2 in	1 in

1994 Proposed Designs Standards for Recreation Trails

	Easier	Moderate	Difficult
ave. grade	5 %	8 %	12 %
max. grade	10 %	14 %	20 %
for a distance of	30 ft	50 ft	50 ft
ave. cross slope	3 %	3 %	5 %
max. cross slope	3 %	5 %	8 %
for a distance of	30 ft	50 ft	50 ft
max. level change	1 in	2 in	3 in

RESEARCH QUESTION

The long term goal of this research plan is to develop appropriate guidelines for ORARs and recreation trails. This pilot research study was conducted in order to test an initial protocol on a small subject group, and to evaluate the need for further research on the accessibility guidelines. The main research question of this pilot study was: Do the "degree of access" categories (easier, moderate, difficult, most difficult) for grade and cross slope match the level of difficulty perceived by persons negotiating that particular environment?

METHOD

Twelve subjects (9 males; 3 females), ranging in age from 28 to 72 years (mean of 41 years), participated in the study. The subject group included: six with spinal cord injury, one with cerebral palsy, one individual who was blind, three weak ambulatory individuals, and one without a disability. Subjects used assistive devices during testing: eight used manual wheelchairs, one used a navigation cane, one used crutches, and one used braces and muscle stimulation.

Subject Performance Tests

Each subject completed five tests to determine his/her level of physical fitness and skill:

1) PWC$_{170}$: Determined the physical work capacity at a heart rate of 170 beats/min using an arm ergometer.
2) Handgrip strength test: Measured maximum force with a Jamar handgrip dynamometer.
3) Speed and muscular endurance test: Determined peak output and total output over a 30 sec period at 120 revs/min on an arm ergometer.
4) Reaction time and acceleration test: Measured the minimum time required to travel up a 2 meter standard ramp from a standing start.
5) Curb climb test: Determined maximum step height negotiated.

Tests of Surfaces

Subjects used a difficulty rating scale to document their perceptions of the difficulty experienced in traversing various grades and cross slopes (Figure 1). Each subject walked/propelled across a flat surface and was told that this represented a "1" on the difficulty rating scale. The maximum cross slope and maximum grade that the subject was capable of negotiating were determined. Subjects were told that their personal maximum results represented a "10" on the difficulty rating scale. Each subject then walked/propelled across the adjustable ramp and difficulty ratings were obtained for grades of 0%, 5%, 8%, 10%, 14%, and 20% with cross slopes of 0%, 2%, 3%, 5%, 8%, and 12% (36 total grade/cross slope combinations).

ORAR/Trail Assessment

Each subject traveled across four different outdoor paths and rated the effort required, using both the level of difficulty rating scale and the rating of perceived exertion scale [5] (Figures 1,2).

Figure 1. Level of Difficulty Rating Scale

1	
2	Easy
3	
4	Moderate
5	
6	Difficult
7	
8	Most Difficult
9	
10	Extreme

Figure 2. Rating of Perceived Exertion Scale

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

RESULTS

Subject Ramp Skills

Results of the tests used to determine the limits of the navigational skills of the subjects are shown below.

Ramp Skills of Subjects

	Mean (±1 S.D.)
min time for 2 m standard ramp	2.2 ± 0.4 sec
max cross slope	36 ± 6 %
max grade – up	30 ± 3%
max grade – down	28 ± 5 %
max curb – up	28.7 ±17.4 cm
max curb – down	28.0 ± 16.6 cm

Difficulty Rating vs. Ramp Configuration

Based upon the average difficulty ratings of the 12 subjects, grades of up to 8% with cross slopes of up to 12% were rated as "Easy." Grades of 10% and 14% were also considered "Easy" if the cross slope was 8% and 5% or less, respectively. Grades of 10% with cross slopes of 12% and grades of 14% with cross slopes of 8% or 12% were considered "Moderate," as were grades of 20% with cross slopes of 8% or less. A 20% grade with 12% cross slope was considered "Difficult."

Overall, there was no significant difference between the difficulty ratings for 2% and 3% cross slope regardless of grade. All other comparisons between groups of grades or cross slopes were significantly different from each other ($p<0.05$).

Factors that Influence Difficulty Ratings

The subjects' difficulty rating for a standard ramp was the only variable which was significantly correlated ($p<0.05$) with the difficulty rating for all grade and cross slope configurations. Other ramp and curb performance variables (2 m ramp time, maximum grade, maximum cross slope, maximum curb height) were also significantly correlated ($p<0.05$) with the difficulty ratings for cross slopes of 3% or greater and for grades of 10% or greater.

Physical fitness variables (PWC$_{170}$, muscular endurance, handgrip) were not related to difficulty ratings for either grade or cross slope, except for grades of 20% which were significantly correlated to aerobic fitness ($r=0.38$, $p=0.01$) and anaerobic power ($r=0.24$, $p<0.05$). Wheelchair users tended to give higher ratings (4.8) for a 12% cross slope than those who were ambulatory (3.9). Subjects with disabilities resulting from cerebral palsy or spinal cord injury who use wheelchairs tended to have higher difficulty ratings at 5% ($p=0.08$), 8% ($p=0.07$) and 12% ($p<0.05$) cross slope settings. Females also tended to have higher difficulty ratings than males when the cross slope was 8% (F=4.0, M=3.4) or 12% (F=4.9, M=4.3).

Grade difficulty ratings were significantly influenced by gender, disability and assistive device use, but not by perceived fitness relative to peers. Females rated the grades of 10% or greater significantly more difficult than the male subjects ($p<0.05$). The subject who was blind had low ratings at all grades. Wheelchair users also had consistently high difficulty ratings at each grade.

Ratings of ORARs/Trails

For all four outdoor paths, average difficulty ratings and ratings of perceived exertion assigned by the subjects were lower than the trail degree of access categories as determined by the 1994 proposed standards.

Ratings of Outdoor Paths

Path	Degree of Access	Ave Difficulty Rating	Ave RPE
Shop Loop	Difficult	Easy (2.4 ±0.9)	10 ±2
East Arbor–up	Difficult	Easy (3.3 ±0.8)	11 ±1
Gasoline Alley	Difficult	Easy (3.3 ±1.4)	12 ±2
East Arbor–down	Difficult	Mod (4.5 ±1.0)	13 ±1

DISCUSSION

The results of this research study have clearly demonstrated the need to re-evaluate the design standards for outdoor recreation access routes and recreation trails proposed by the Outdoor Recreation Area Advisory Committee in 1994. Based upon the results of this pilot study, new recommendations were developed (see tables below). The new 1995 recommendations for recreation trails consist of four categories and a fifth "Extreme" category for trails that exceed the "Most Difficult" specifications. The main difference between these recommendations and those proposed by the Advisory Committee in 1994 is found in the cross slope values. Cross slope values are significantly higher in the new 1995 recommendations, while grade values are only slightly higher.

1995 Research Outcome Recommendations for Outdoor Recreation Access Routes

	Easier	Moderate	Difficult
ave grade	5 %	8 %	10 %
max grade	8 %	12 %	14 %
for a distance of	10 ft	30 ft	30 ft
ave cross slope	3 %	5 %	8 %
max cross slope	5 %	8 %	12 %
for a distance of	10 ft	30 ft	30 ft
max obstacle height	1/2 in	1 in	2 in

1995 Research Outcome Recommendations for Recreation Trails

	Easier	Mod	Diff	M Diff
ave grade	8 %	10 %	14 %	20 %
max grade	14 %	14 %	20 %	30 %
for a distance of	10 ft	30 ft	30 ft	30 ft
ave cross slope	5 %	8 %	12 %	16 %
max cross slope	12 %	12 %	16 %	20 %
for a distance of	10 ft	30 ft	30 ft	30 ft
max obstacle ht.	1 in	2 in	4 in	8 in

Future research will include extensive subject evaluations of outdoor environments with various conditions (grade, cross slope, obstacles, surface, and length) and objective measurements of the work required to negotiate these environments. The results of this study will be used to define the protocol for this larger research study.

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DRAFT TEST METHOD FOR THE MEASUREMENT OF SURFACE ACCESSIBILITY

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ABSTRACT

ADA Accessibility Guidelines specify that ground and floor surfaces should be firm, stable, and slip-resistant. These specifications are subjective; objective methods for assessing surfaces are not given. Test methods for measuring surface firmness and stability are currently under development. One of these test procedures, the wheelchair rolling resistance test, utilizes the SMART$^{\text{wheel}}$ to measure the work required to travel across different surfaces. This draft test procedure was evaluated on various surface types ranging from level rubber matting to indoor carpeting to pea gravel. Measurements were also taken on an adjustable ramp set to different grades, cross slopes and grade/cross slope combinations. The results demonstrated the feasibility of using this test procedure as an objective method to measure surface firmness. Comparisons were made between the work required to negotiate the level surfaces and the work required to propel up various ramp angles. Future work will include the determination of the specific ramp angle to be used as the performance criteria for accessible surfaces.

BACKGROUND

Current ADA Accessibility Guidelines for buildings and facilities contain subjective technical requirements for ground and floor surfaces. According to ADAAG, accessible routes must be firm, stable and slip-resistant. Test methods exist for measuring slip resistance, but not for surface firmness or stability as it relates to access for people. Surface firmness primarily influences the effort required to roll/propel a wheelchair across the surface, while surface stability mainly affects wheelchair turning and maneuvering, and access by cane, crutch, and walker.

In 1993, a Phase I research project was conducted to evaluate the feasibility of developing prototype devices to objectively measure the characteristics of a surface that affect its degree of accessibility [1]. Wheelchair rolling resistance was used as an indicator of the firmness of the surface and was determined by measuring the force required to pull a loaded wheelchair across the surface. This method was found to be unreliable. An alternative wheelchair rolling resistance test method was also developed. This method utilized the SMART$^{\text{wheel}}$ [2] to determine the amount of work required to travel across the surface. The work accomplished during this Phase I research project was the impetus for the development of a draft ASTM standard specification for the firmness of surface systems used under and around playground equipment.

RESEARCH OBJECTIVES

The measurement of surface firmness applies to all paths of travel, indoor and outdoor. Ideally, the same test method should be used to assess all types of surfaces ranging from indoor carpeting to outdoor recreation access routes and playground surface systems. The objectives of this research were to evaluate the wheelchair rolling resistance test procedure by measuring a wide range of surface types, and to compare the surface measurement results with measurements of the work required to roll up/across various grades and cross slopes.

METHOD

Test Equipment

The SMART$^{\text{wheel}}$ is a specially instrumented main wheelchair wheel that is capable of measuring forces applied to the pushrim [2]. The SMART$^{\text{wheel}}$ was used on a standard rehab wheelchair (Quickie 2 by Sunrise Medical) with pneumatic rear tires and front casters, and a total weight of 15.5 kg (34.2 lbs.). During testing, the wheelchair was propelled by a 75.5 kg (166 lb.) able-bodied test subject. A 40-60% total weight distribution was used; 40 ±2% of the total weight of the wheelchair and test subject was distributed over the front casters; the rear wheels supported the remaining 60 ±2% of the total weight.

Test Surfaces

The test surfaces were divided into six different categories. The adjustable ramp was firm, stable and slip resistant (coefficient of friction greater than 0.8). The trail surface was hard-packed decomposed granite. The indoor accessible carpet used in testing had level cut pile 1.2 cm (0.47 in) in height and was not used with padding. The inaccessible carpet had a pile height of 2.1 cm (0.83 in) and was used with a 0.9 cm (0.34 in) composite foam pad.

1) Ramp grades: 2%, 5%, 6%, 7%, 8%, 10%, 14%, 20%, and 24% (1:50, 1:20, 1:16, 1:14, 1:12, 1:10, 1:7, 1:5, and 1:4, respectively)
2) Ramp cross slopes: 2%, 3%, 5%, 8%, 12%, 14%, 16%, and 20%

3) Ramp grade/cross slope combinations: 8%/3%, 8%/5%, 8%/8%, 14%/5%, and 14%/8%
4) Playground surfaces (all level): rubber, 2 engineered wood fiber surfaces, generic cedar chips, generic bark chips, #1 plaster sand, and 3/8" pea gravel
5) Trail surface: 2%, 8%, and 14% grade; 2%/5% and 8%/5% grade/cross slope combinations
6) Indoor inaccessible carpet: 2%, 8%, and 14% grade; 2%/5%, 8%/5%, and 14%/8% grade/cross slope combinations; 2% grade accessible carpet

Test Procedure

A computer data acquisition system recorded the forces measured by the SMART^{wheel} at a frequency of 50 Hz. Only the forces tangential to the pushrim and parallel to the direction of travel were measured. Electronic triggers were placed 2 m (6.56 ft) apart and signaled the beginning and ending of each trial.

The test subject propelled the wheelchair across the test surface a distance of 2 m using four uniform pushes. Each trial was completed in 7.0 ±0.5 sec. Trials were acceptable if the wheelchair came to a stop at the end of the 2 m test run such that all the energy exerted by the test subject during the last propulsion stroke was used to move the wheelchair the specified distance. A minimum of seven trials were conducted on each test surface. Four of the surfacing materials (engineered wood fiber surfaces, generic cedar chips and bark chips) were tamped prior to each trial to remove any tracks created by the wheelchair during the previous trial. Pushrim force measurements were analyzed to determine the amount of work required to negotiate a each test surface.

Data Analysis

Torque versus time plots were generated for each trial and the impulse (area under the torque curve) was calculated using a trapezoidal approximation. The amount of work required to wheel across each test surface was determined by calculating the total impulse for all four propulsion cycles and dividing by the time to complete the trial. For each test surface, an average of five trials was calculated to determine the average work required to negotiate the test surface.

RESULTS

Work Required vs. Ramp Configuration

A total of 22 different ramp configurations were objectively measured. As expected, increasing the grade of the ramp increased the amount of work required to travel up the ramp. Grades of 14%, 20%, and 24% required 70%, 130%, and 180% more work, respectively, than the standard 8% grade ramp.

Propelling the wheelchair such that it came to a stop at the end of the 2 m test run was difficult to achieve on surfaces with cross slope only (no grade) and little rolling resistance. Therefore, a slight grade of 2% had to be used with all cross slope ramp tests in order to achieve accurate and repeatable results. Similar to the ramp grade results, the work required to travel across the ramp with cross slope increased linearly with the amount of cross slope. A cross slope of 20% required 70% more work than a 2% cross slope.

Multiple linear regression analysis was performed to determine the effects of grade and cross slope on work required. This regression explained all of the variation in the work required and was highly significant ($p<0.01$). As expected, both grade ($p<0.01$) and cross slope ($p<0.01$) were found to be significant factors that affect the work required to traverse the ramp. Based upon this analysis, an equation for predicting the amount of work required for any ramp configuration was determined:

$$\textit{Work Required (N-m)} = [2.37 \times \textit{Grade}] + [0.70 \times \textit{Cross Slope}] + 3.36$$

The amount of work associated with ramp configurations that can not be measured according to the rolling resistance test procedure could then be estimated using this equation.

Comparison of all ramp results indicated that cross slopes of 16% or less require less work to negotiate than the standard 8% ramp with no cross slope. The work required to travel across the ramp with a 20% cross slope was not significantly different than the ramp with an 8% grade and 3% cross slope. These results also showed that grade/cross slope combinations of 8%/8% and 14%/8% required significantly less work than grades of 10% and 20%, respectively.

Work Required vs. Surface Type

All playground surfacing materials were significantly different ($p<0.01$) except the two engineered wood fiber surfaces. Compared to the engineered wood fiber surfaces (15.9 N-m, 16.8 N-m), generic cedar chips (21.3 N-m) required about 30% more work to negotiate, and generic bark chips (25.4 N-m) required about 55% more work. Both engineered wood fiber surfaces required significantly less work than the ramp with a 6% grade ($p<0.01$) and an average of 25% less work than the standard ramp with an 8% grade. No significant difference was found between the cedar chips and the 8% grade ramp ($p>0.20$). The work required to negotiate bark chips exceeded that of the ramp with an 8% grade by 16.5%.

Testing could not be conducted on sand and pea gravel according to the draft test procedure. On both surfaces, the front casters imbedded into the surface such that the test subject was incapable of propelling the wheelchair.

The trail surface required 9-24% more work to negotiate compared to the corresponding grade/cross slope ramp configurations. The inaccessible carpet was 23-172% more difficult to negotiate than the ramp and this percentage decreased as the work required increased.

Three surfaces (ramp, trail, and inaccessible carpet) were examined more closely to determine the effects of grade, cross slope and surface on the amount of work required. Grades of 2, 8, and 14% in combination with cross slopes of 0, 5 and 8% were compared. Within this small group of test surfaces, the amount of work required was not related to cross slope. Work required to negotiate the test surface was significantly related to grade ($p<0.001$) and surface ($p<0.005$). The effects of surface type on the amount of work required decreased as grade increased. In other words, surface type contributed less to the differences in the amount of work required at steeper grades compared to lower grades.

Comparisons (two tailed t-test) made between all test surfaces revealed that the following groups of test surfaces were not significantly different:

- accessible carpet with 2% grade;
  one engineered wood fiber surface ($p>0.20$);
- ramp with 12% cross slope,
  one engineered wood fiber surface ($p>0.20$);
- ramp with 8% grade, inaccessible carpet with
  2% grade, generic cedar chips ($p>0.20$);
- ramp with 8% grade/5% cross slope, bark chips,
  inaccessible carpet with 5% cross slope
  ($p>0.20$);
- ramp with 14% grade/5% cross slope,
  trail with 13% grade ($p>0.20$);
- ramp with 14% grade/8% cross slope,
  trail with 13% grade ($p>0.20$);

DISCUSSION

The draft wheelchair rolling resistance test procedure was used on a wide range of surface types. Limitations occurred on surfaces that were clearly "inaccessible" (sand and pea gravel) and on surfaces that provided very little rolling resistance (rubber and ramps with cross slope and no grade). The repeatability and sensitivity of the test procedure were good. The test procedure was sensitive enough to differentiate between small changes in grade, cross slope, and surface type. Future testing will include the use of three different test subjects to further evaluate the repeatability of the test procedure. Funding for research to develop a portable device to quickly and easily measure firmness is pending.

The draft test procedure provided objective measurements of surface firmness that could be compared with the work required to negotiate various ramp angles. ADAAG specifies maximum slopes for accessible ramps (1:12 or 8.3%). Therefore, it is feasible that the work required to negotiate a specific ramp angle could be used as the ADAAG pass/fail performance criteria for accessible surfaces. Additional research must be conducted to determine the appropriate reference ramp angle to be used.

For outdoor recreational environments, pass/fail performance criteria is not desired. Instead, a means for disclosing objective information about the firmness of an outdoor recreation access route or recreation trail is needed. This firmness measurement could be used to classify the surface into categories (e.g. paved, hard, firm, soft, very soft).

This research focused on test methods for assessing surface firmness. Future research to investigate test methods and develop devices for measuring surface stability has been proposed and funding is pending.

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PERSONAL FREEDOM: A WEARABLE INTERACTIVE UNIVERSAL ACCESS DEVICE

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ABSTRACT

For persons with disabilities, personal freedom is directly related to the ability to successfully *access* and *interact* with the world around them. The purpose of the *Personal Freedom* project is to develop a universal and interactive interface/access device for persons with disabilities. The investigators envision this interface as modular "wearable" hardware controlled by software that exhibits a sense of "shared responsibility" in meeting the particular needs of the user. Infra-Red (IR) and Radio Frequency (RF) coded commands and communications channels will be employed to access and control devices and to link the user to information sources.

BACKGROUND

In the past, in a less mechanized society, differences in functional abilities were mediated through interpersonal relationships and a sense of shared responsibility for the successful functioning of each person in the community. Unfortunately, our society has become increasingly mechanized. While this mechanization may have been designed for purposes of convenience and efficiency, in many cases it was *not* designed for universal accessibility. And, in addition, the new mechanisms may have completely replaced persons who would have taken responsibility for the successful interactions of persons with disabilities. Push-button panels have replaced the elevator operator, automatic doors have replaced the "doorman," Automatic Teller Machines (ATMs) are now replacing your personal bank teller, kiosks in malls are replacing the person in the information booth, kiosks in Post Offices are beginning to replace the postal clerk, kiosks in libraries are beginning to replace the "helpful" librarian, computers and word processors are replacing secretaries, and computer interfaces to the National Information Infrastructure (NII) or "information highway" are beginning to replace information clerks and government information offices. Getting needed tax advice, renewing your drivers license and registering to vote may soon all take place via public kiosks or computer interfaces. [1]

In November, 1994, the Technology Research Working Group stemming from the NIDRR Project Directors Meeting in January 1994, identified eight priority needs for persons with low vision. Seven of these eight priorities related to access issues: (1) accessing signs, directories and routing information for navigating large malls and transit plazas; (2) accessing video information; (3) accessing visual displays found in ATMs, home appliances, and other devices employing liquid crystal and light-emitting diode displays; (4) accessing advanced technology in the home that employ keypads, interactive displays, etc.; (5) for persons with both visual and auditory impairments accessing (being apprised of) warning sounds, fire alarms, sirens, bells, telephones, etc.; (6) accessing electronic information systems; and (7) designing universal interfaces for access by all persons with disabilities. [2]

The challenge is thus to design a universal interface that offers persons with disabilities equitable access to our increasingly mechanized environment so that they may successfully interact with this environment in the performance of their ADLs. Further, (1) the user should be able to "personalize" this interface to his/her own needs and abilities, (2) this personalized interface should be consistent across all activities and interactions, and (3) it should be present and available wherever and whenever it is needed.

RESEARCH QUESTIONS

1. Can personal universal interface hardware be designed with the flexibility to accommodate the access needs of all persons with disabilities as described above, including: (a) access control of devices in the home and in the outdoor environment, including home appliances, thermostat, personal vehicle accessories, public elevators, automatic doors, street crossing buttons, toll gates, etc.; (b) access to ATMs, information kiosks, libraries, and post offices, etc.; (c) access to city street, mall and transport plaza orientation and navigation information; (d) interactive access and control of computers and computer programs; and (d) interactive access of NII information and resources?

2. Can the above described universal hardware be miniaturized to the extent that it may be unobtrusively and inconspicuously worn (or carried) by the user so as to be present wherever and whenever it may be needed?

3. What are the most appropriate hardware interfaces for each disability population and how may they best be integrated into a "wearable" device?

4. Can interactive interface software be designed that "shares responsibility" for successful

interactions through (a) demonstrated respect for the person's needs; (b) open communication of device operation, procedures, warnings, problems, etc. that is phrased in a language appropriate to the user's level of understanding; and (c) an interactive structure that allows the user to learn the best means of performing a task through active dialogs and/or connects the user with a person who can help?

5. Are existing RF and IR communication links adequate to provide access to the ever-changing technological interfaces to information, devices, control systems, etc.; and if not, what is needed and can this be easily and modularity integrated into universal design hardware?

6. Can software be devised to offer interactive access and control of computing systems that employ Windows operating software, Unix X-Windows software, etc., and can the access software also keep pace with operating systems yet to be developed?

7. Can software be devised to offer access to World Wide Web communications interfaces that in addition to standard text include graphical page layouts with unconnected pieces of text, two-dimensional and three-dimensional graphics and pictures, and two and three-dimensional active sound files?

METHODOLOGY

The investigators are developing initial hardware to meet the needs of persons with spinal cord injury. However, modularity and interface generality will be maintained so that the same base hardware may be used by other disability groups. In this way, the immediate needs of a particular population can be addressed while developing a modular hardware base unit that can be employed to serve the needs of other populations as well. The operating software will be constructed in a similar fashion, in modules, many of which will be generalizable to other populations.

The hardware chosen for this design is comprised of modular wearable Personal Computer (PC) components. Employing this modular hardware gives the designers (and users) the flexibility to employ processors that suit current needs, and the ability to change to a more powerful processor when needed in the future. This hardware will also be configured for various information protocols for the implementation of many types of input and output hardware. Though voice interactive hardware is currently being developed, it will be possible to easily add in (or replace the speech output interface with) a video interface or braille interface. Also, by employing PC hardware, software development is simplified. Anyone with a desktop PC can develop software for this wearable PC device. This makes it possible for any programmer to develop and modify software for this device.

The communications hardware employed will also be modular and easily changed in the future. Initially, this hardware will include RF and IR circuits capable of controlling X-10 devices and IR remote-control devices. It will also include an implementation of the industry standard IR protocol (IRDA). Employing IRDA communications, the investigators will have the ability to monitor device operation and modify software quickly with from a desktop computer. IRDA software will also be designed to give the user the ability to access and control a desktop computer either via the serial port, or by emulating a wireless keyboard and mouse. A digital RF transceiver will be developed, offering computer network links and Internet connectivity.

Interaction with ATMs and kiosks will require the cooperation of ATM manufacturers and banks; however, the investigators are aware of talks in progress that would implement a secure IRDA link to ATMs [3]. Then, given the establishment of this protocol for ATMs, it should not be difficult to have this implemented in kiosks as well. Further, if kiosks are linked to Internet, then interacting with the kiosks could be accomplished without the need to travel to the kiosk—an obvious convenience for many people.

Interaction with home appliances is being driven by the home automation industries. This will eventually give a home PC access to appliances, thermostats, etc. Once the data protocol is established for this, it will be incorporated into the wearable interface.

Development of interactive "dialog" software will be accomplished through the use of fuzzy logic /neural network development system tools (MatLab®). This system gives the investigators the ability to develop and test designs that employ fuzzy logic/neural networks and to then compile them into computer code that can be ported to the wearable device. In particular, this will be employed to develop a small-order "association memory" system to assist in word recognition and the determination of associated actions to take. The intent is to give the wearable device a means of learning appropriate responses from past history. In addition, this software is to give the user the ability to establish a training dialog with the wearable interface. And finally, these tools will be employed to make synthetic speech more "human" sounding, by learning how to put accents into words and phrases that better bring out intelligibility and meaning.

As wearable prototypes are developed, disabled persons from the community will be asked to "sit in" on evaluation meetings with experts and to critique device development. Subjects will also be employed to test prototypes at various stages in their development. To this end, they will be asked to take the prototypes home, use them for several weeks and provide a critique.

Software specific to the needs of spinal cord injury will be completed and evaluated first. Then development of software and hardware interfaces for persons with low vision will commence, followed by interface development for persons with hearing disabilities and persons who experience both hearing and visual disabilities. The investigators also plan to develop software/hardware for persons with cognitive disabilities. And, again, all these interfaces will be developed around the original modular hardware base and operating system.

Results of all subject testing will be analyzed relative to each subject grouping. Qualitative elements of tests will be descriptively presented through measures of central tendency and dispersion. Tabulation and graphic representations will be employed when appropriate. The objective data will be evaluated with multiple paired t-tests or repeated measures ANOVA to identify main effects and interactions of condition by device. Subjective data will form the basis for specific case studies that will complement the objective findings by identifying specific examples of advantages and disadvantages of the prototype device(s).

RESULTS

Work began in April, 1995, with the design and development of User-based VOice Interactive Control of the Environment (U-VOICE) for persons with spinal cord injury. Two working prototypes (wearable devices) have been developed that employ modular personal computer hardware from Adaptive Systems, Inc. The prototypes also employ voice-recognition/synthetic speech hardware from Voice Connexion, and an RF and IR/IRDA circuit board designed by the investigators. The RF circuit is capable of transmitting X-10 control codes. The IR circuit is able to learn and transmit entertainment system (TV, VCR, stereo, etc.) control codes, and effect IRDA protocol communications with a desktop computer.

Through voice-only interactions a person is currently able to train the interface device to recognize commands, set-up X-10 code sequences, and tell the device to learn IR codes from a hand-held remote control. Once learned, a simple voice command can then be used to control devices. Control of elevators is effected through the use of Infra-Link® IR codes. The wearable interface will correctly call an elevator and select panel buttons for any elevator employing the Infra-Link® hardware. It will also control Infra-Link® automatic doors and van lifts.

As of this writing, these prototypes are being tested by the investigators, and interactive speech algorithms are being developed. Professionals and persons with spinal cord injury will be invited to evaluate the prototypes in March, 1996.

DISCUSSION

The development of the suggested *Personal Freedom* access interface is a long term project that will require the cooperation of rehabilitation professionals, industry leaders, commercial leaders, and members of each disability group. It requires (1) a commitment to the idea that equitable access to information by all persons is desirable and possible, (2) a sense of mutual respect for people of diverse capabilities and backgrounds, and (3) a true concern for the personal freedom of all people. The face of technology is changing very rapidly and many competitors are developing technologies that seem to continuously outdate each other. This has made it very difficult predict the types of technology and communications that will prevail by the year 2000. However, it is clear that access to this technology will be imperative for the everyday performance of ADLs, and that the development of universal interfaces for persons with disabilities must proceed in spite of these uncertainties. Consequently, the universal interface hardware and software must be highly flexible and modular. The challenge is considerable, but the rewards to persons with disabilities are great, and if successful, the *Personal Freedom* access interface will be universally employed by persons across the spectrum of disabilities.

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THE ROLE OF INDIVIDUALS WITH DISABILITIES, FAMILY MEMBERS, AND PROVIDERS IN THE HOME MODIFICATION PROCESS IN RURAL NORTH CAROLINA

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ABSTRACT

This paper reports on an in-depth examination of the role of the respondents, their families, providers, and volunteer groups in obtaining and installing accessible features in the homes of adults with disabilities in rural areas. The study focused on three key questions: who identified the need for a modification, were product/materials purchased or donated and by whom; was construction/installation labor contracted for or donated and by whom. In the majority of cases, the necessary materials/products were purchased and the necessary labor donated. Individuals with a disability did not identify the need for the majority of observed modification, although they did pay for a majority of those that were purchased. Staff of local agencies that assisted in home modification service delivery reported that utilization of available services was negatively impacted by lack of awareness among consumers about programs and fragmentation of services.

BACKGROUND

Accessible housing, like all housing, can be conceptualized as a process as well as a product. There is interest in understanding how accessibility is achieved as well as what is achieved. This study built on two earlier studies that examined the presence and absence of accessible features and home modifications and their impact on ease and independence in routine daily activities for an urban/suburban, moderate income sample (n=486) and a rural, lower income sample (n=123) of adults with mobility impairments. (1,2) The types of accessible features adopted by the majority ($\geq 50\%$) of individuals in both samples were similar for entries (e.g., adequate door width, maneuvering space, and ramped access), kitchens (e.g., maneuvering space, storage within reach), and bathrooms (toilet seat and sink height appropriate, maneuvering space adequate). However, the adoption rate for specific accessible features was often higher among the rural, lower income sample. For example, a larger percentage of the power wheelchair users in the lower income, rural sample than the more affluent, urban/suburban respondents in reported adequate maneuvering space at the entry, adequate access space at the oven, kitchen storage within reach, shower grab bars, and toilet seat at preferred height .

We had expected the lower income and more rural sample to have fewer accessible features in their homes -- we had assumed they had access to fewer and/or less extensive home modification services and modifications would be less affordable for them. However, they appeared to have been at least as successful as the more urban/suburban and affluent sample in addressing their accessibility needs. Thus, the comparative results were not expected and raised a number of questions about the home modification process utilized by the rural respondents. In other words, what was the "process" by which their housing "product" had been obtained?

RESEARCH QUESTIONS

The study addressed three major questions:

1. Who identified the need for a modification?

2. Were product/materials purchased or donated and by whom?

3. Was construction/installation labor contracted for or donated and by whom.

METHODS

The initial study to determine presence and absence of accessible features and home modifications involved personal interviews with 128 individuals in two rural counties in Piedmont North Carolina selected on the basis of their comparatively high concentration of persons with disabilities (based on the 1990 census). Respondents were located through contact with agencies providing services to people with disabilities, informal social networks, and local ministers. (2) Participants from the initial study who had indicated they could be contacted for future studies (n=95) were contacted to determine if the accessible features in their homes were added while they were living there, and, if so, how the modifications were achieved. Some of these initial study participants could not be reached because they had unlisted telephone numbers, did not have a telephone, or were deceased. A total of 62 (of 95) participants from the initial study participated in the follow-up study, and 49 (80%) had made modifications to their homes while they lived there.

Documentation of the presence or absence of accessible features and home modifications for the subjects included in the study described here were obtained in the initial study through home visits and personal interviews. (2) In the follow-up study, described here, a telephone interview methodology and limited site visits were used. For each accessible feature and home modification present in the home of each respondent, a "history" was obtained that documented who identified associated needs and solutions, who paid for or provided materials, and who paid for or provided labor.

Results

Data were obtained for a total of 122 features in the homes of the 49 respondents, which had been modified during the respondents' residency. About half (53%) of the modifications were less than 5 years old.

The need for less than one-fourth (23%) of the modifications/accessible features was identified by the respondent. The need for the large majority had been identified by a family member (38.5%) or by someone outside the family (e.g., local health care and service providers) (36.1%). Materials/products needed to create 71% of the modifications/accessible features had been purchased and 29% had been donated. For those modifications/accessible features involving the purchase of materials/products, family and friends (67%), the respondent (17%), and someone outside the home (15%) or unknown (1%) had paid for these purchases. In the case of donated materials/products, the large majority (91%) were provided by service agencies. Labor to build or install over half (55%) of the modifications. For the remainder, labor was donated (e.g., community service project), was purchased for 25%, and 16% did not require labor to install (e.g., a tub stool). In about 10% of the cases the respondent did not know how labor costs were handled. Donated labor for individual modifications was provided by the respondent (4%), family/friends (54%), service providers (41%), and unknown (1%). Purchased labor for individual modifications was paid for by family/friends (3%) and service providers (93%).

In addition to respondent interviews, information about sources of assistance for accessible modifications for people with disabilities was collected for the two counties. Agreement existed among the agencies that services and resources are available to assist those who need assistance in acquiring home modifications or design feature enhancement. However, utilization of available services and resources is negatively affected by (1) lack of awareness by targeted audiences about services, (2) lack of information on how to apply for assistance, and (3) lack of coordination in the delivery of necessary services.

DISCUSSION

The results of this study suggest that different factors are critical to different components of the process of obtaining home modifications/accessible features in rural areas. Materials/products tended to be purchased and the individual with a disability was the most common source of payment. Labor tended to be obtained in a way that did not involve an outlay of money on the part of the individual with a disability. Family/friends were the most frequent source of no-cost labor. These results are consistent with anecdotal evidence from service programs in rural areas that monies to purchase materials and labor are limited, available funds are often used to obtain materials that may be too costly for individuals to afford (e.g., pressure treated lumber for ramps), and they must rely heavily on community and civic service groups to get the work done.

Other studies have found that reliance on volunteer groups and family members can result in variability in the craftsmanship of modifications, which may impact their usability and safety.(3) For example, the geometries involved in ensuring a ramp begins and ends at the desired points and level with the abutting surfaces may present difficulties for inexperienced, weekend carpenters. Technical information targeted to those with limited construction skills and limited experience in making modifications would help to address these needs. Additionally, documentation of service delivery programs that work, given the limited monies that are often available to purchase materials and provide labor, are needed. Finally, available services need to be better advertised. Some groups, such as older individuals with age-related disabilities, may be particularly disadvantaged in their awareness of available services to assist them in improving the accessibility and safety of their homes.

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ACCESSIBILITY REQUIREMENTS FOR RAMP SLOPE: RESULTS OF HUMAN SUBJECTS TESTING

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ABSTRACT

This paper reports the results of a study to evaluate the usability of the range of ramp slopes allowed under the current ADA accessibility guidelines. One hundred seventy-one subjects of all ages and using different types of mobility aids traversed a 30 foot ramp varying in slope from 1:8 to 1:20. Data was recorded for pulse rate, energy expenditure, rate of travel, distance traveled, and the location of rest stops. Findings show that among all subjects only a few manual wheelchair users had difficulty traversing all 30 feet in ascent, even on slopes as steep as 1:8.

BACKGROUND

Section 4.8 of the Americans with Disabilities Act Accessibility Guidelines (ADAAG) specifies that ramp slopes should not exceed a ratio of one inch in vertical rise to twelve inches of horizontal run for a maximum rise of 30 inches. Although this requirement is consistent with other accessibility standards, over the years there have been questions concerning the adequacy of the 1:12 slope as well as the maximum slope in alterations where ADAAG allows slopes steeper than 1:12 for rises up to 6 inches.

Although current standards for ramp slope and length have been based upon a considerable amount of research over the past 25 years, most studies used fairly homogeneous populations of young males with good upper body strength and stamina (e.g., Elmer, 1957; Canale, Felici, Marchetti & Ricci 1991). Recently, however, advances in medical sciences, increased survival of people from accidents, and development of new assistive devices have resulted in greater numbers of independent frail older people and people with severe disabilities. As a result, the validity of existing requirements for older users and users with more severe functional limitations has been questioned with increasing frequency. In fact, at least one study (Steinfeld, Shroeder & Bishop, 1979), supports this argument, suggesting that ramp slope vary between 1:16 and 1:20 based on a sample of individuals with more restricted functional abilities and a wider range of ages.

RESEARCH QUESTIONS

In order to develop recommendations for accessibility guidelines for ramps to be considered in future revisions to ADAAG, the study addressed the following questions: What are the maximum and optimum slopes and distances that individuals with different disabilities can traverse safely? What is the relationship between ramp slope and length? For people with what types of mobility impairments are these slopes and lengths appropriate, and does it vary by disability?

METHOD

Apparatus. A 36 in.-wide, 30 ft.- long, aluminum ramp with a triple row of tubular aluminum side railings (at 8, 21.5, and 34 in. was adjustable to seven calibrated slopes: level, 1:20, 1:16, 1:14, 1:12, 1:10 and 1:8.

Procedures. Two baseline trials (forward and back) with the ramp in the level position were conducted first. Following the two baseline trials, subjects were asked to ascend and descend 6 additional slopes (1:8, 1:10, 1:12, 1:14, 1:16, and 1:20), thus comprising a total of 14 trials. In order to minimize ordering effect, the slopes were presented in a random order.

Participants were instructed to traverse the ramp at a comfortable pace, pausing as needed and simulating the way they would typically use a ramp. At the end of each trial, pulse and oxygen saturation levels were recorded. When subjects' pulse and oxygen levels stabilized, they were asked to complete the next trial.

Data Collection. Seven dependent variables were observed for each ramp trial: total distance; total time; rest stops (i.e., number, duration, and location); pulse rate; oxygen saturation (i.e., energy expenditure); hazardous maneuvers (e.g., control of speed and occurrences of slipping); and assistance.

RESULTS

Sample. A sampling frame was established based on age and type of mobility device used. The sampling frame called for a sample of 192 subjects in six age categories using nine types of mobility aids -- manual wheelchairs; power wheelchairs; scooters; canes; crutches; walkers; prostheses; orthoses; and no mobility aid, but activity limitation.

Only subjects who were generally in good health were permitted to participate in the study. A total of 171 subjects representing 43 of the 51 cells in the sampling frame participated. Seven of the eight cells for whom no participants were found were single-representative cells, the eighth was a two-person cell. Older participants over 75 years of age accounted for the largest number (10) of missing subjects. However, because this age group was the largest in the sampling frame, 85.7% of the targeted number of subjects participated. By mobility category, subjects who used canes or crutches had the largest shortfall (14) from the sampling frame. However, this subgroup accounted for the largest single cell in the sampling frame (99). As a result, 85.9% of the targeted sample was tested. Finally, the ratio of males (41.5%) to females (58.5) remained true to the sampling frame (42.7% to 58.3%).

Distance Traveled. The sample as a whole had little trouble in ascent, completing 1164 out of 1181 trials (98.6%), and had even less difficulty in descent, completing 1179 trials (99.7%). However, the incomplete trials is examined by mobility category, 15 of the 17 (88.2%) were by subjects who used manual wheelchairs and the remaining two (11.8%) were by those who used canes.

Although the two incomplete trials by cane users appear to random occurrences and may be due to the effects of fatigue, about 10% of the trials by wheelchair participants were unsuccessful. Not surprisingly, the three steepest slopes accounted for 80% of the incomplete trials. Moreover, the same five subjects were responsible for all of the incomplete trials. One subject failed to complete all six slopes, two additional subjects failed to complete the three slopes steeper than 1:14, one additional subject failed to complete slopes greater than 1:12, and one additional subject failed at 1:8. Finally, it is interesting to note that the five the subjects who failed to ascend 30 feet were all women. Four of the five were over 65 years of age.

Rest Stops. Of the 1179 ascent trials only 24 (2.0%) involved the participant stopping to rest. Subjects who did not complete a trial stopped more often (1.24 stops per trial versus .01 per trial), and at shorter distances (7.44 feet for rest stop 1 and 12.83 feet for rest stop 2 versus 16.98 feet and 25.75 feet, respectively) than those who completed the trials. Moreover, slope did not to impact number, distance, and duration of stops.

Rate of Travel. The overall trend, with few exceptions was that speed decreased as slope increased from 1:20 to 1:8. Although the decrease in speed within each mobility aid subgroup was generally not significant, the downward trend for each is clearly shown in Figure 1. This is particularly evident within the manual wheelchair group where speed decreased by 50% between the level and a 1:8 slope. A second trend was the difference in mean speed across mobility subgroups. People with different mobility aids traveled at different rates of speed, regardless of slope. However, with the exception of manual wheelchair users, increased ramp gradient had the same effect on all subjects regardless of subgroup. Although slope did affect manual wheelchair users, the effect was equally evident across all slopes, not just the steeper gradients, as one might expect.

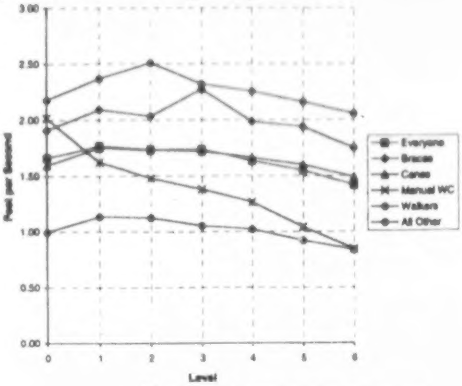

Figure 1. Mean Rate of Travel

Pulse. For the sample as a whole, there was almost a perfect linear relationship between slope and change in pulse (Figure 2). However, such a linear relationship does exist for any of the mobility aid subgroups. In fact, none of the ambulatory subgroups had significant changes in pulse at any of the seven ramp slopes tested. In contrast, manual wheelchair users had significant changes in pulse up to slopes of 1:14, indicating that slope had a greater impact on this group. However, the impact leveled out at 1:14 with no significant differences due to slope until 1:8.

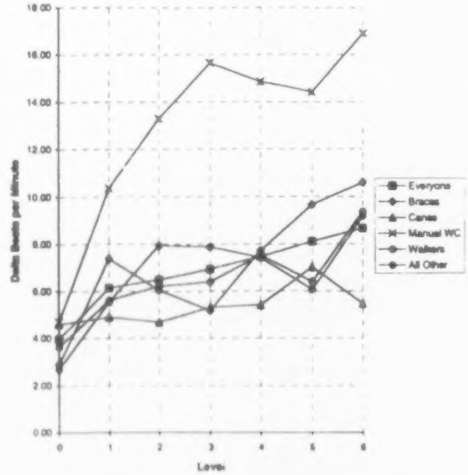

Figure 2. Mean Change in Pulse

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Oxygen Saturation. There were no significant differences in the mean measures of oxygen saturation either within or across groups. Not only is this surprising, but because exertion is really only evident when saturation begins to fall below 90% (particularly as saturation approaches 85%), the sample as a whole (with a mean range of 98.24% to 99.77% saturation) clearly did not exhibit signs of exertion. In other words, 30 feet at any of the slopes does not appear to be a strenuous task for any of the mobility aid subsamples.

DISCUSSION

Although not particularly surprising, the data indicate that none of the factors of interest in this study - slope, mobility aid, gender, and age -- had much of a bearing on subjects' ability to or amount of effort expended while descending ramps of any slope. However, a number of factors, most notably the interaction between ramp slope and manual wheelchair users had an impact in ascent.

Distance traveled is perhaps the most notable evidence suggesting that slope impacts performance by wheelchair users. Of the 151 ambulatory and "other" subjects, only two, apparently random cases (both involving cane users at shallow gradients), resulted in subjects terminating prior to reaching the top of the ramp. In contrast, only 85% of the participants who used manual wheelchairs were able to traverse 30 feet at a slope of 1:12, 80% were able to traverse 30 feet at 1:10, and 75% were able to traverse 30 feet at 1:8. While the percentage of subjects who completed the entire length at the two steepest slopes is higher than expected, the relatively large percentage of manual wheelchair users failing to traverse all 30 feet indicates that slopes steeper than 1:12 at distances of 30 feet is probably too difficult for this population. In fact, 30 foot distances between level rest stops at 1:12 may be too steep for certain segments of the wheelchair population, most notably those who are older and female. This is further evidenced by the increased number of rest stops required by manual wheelchair users in comparison to the rest of the sample.

When rate of travel is considered the data indicate that either the ramp gradients or the 30-foot distance, or both, are sufficient to dramatically impair subjects' rate of travel. However, whereas increased ramp slope tends to affect all of the ambulatory participants and those in the "other" subgroup equally, manual wheelchair users have a significant decrease in speed between the baseline and a 1:14 slope. However, the insignificant increase in rate of travel beyond a slope of 1:14 suggests that there is probably a minimum rate of travel that they must keep up to maintain forward propulsion and that rate was reached at a slope of 1:14.

Manual wheelchair users, unlike the rest of the sample, also experienced a significant increase in pulse rate between the baseline and a slope of 1:14. After 1:14 pulse change leveled out. This finding further supports rate of travel data, indicating that 1:12 or 1:10 may not be any more strenuous than 1:14. Moreover, when the oxygen saturation data is considered, a 30 foot distance is not overly strenuous, even at the steepest slope, thus suggesting that even though pulse rate hits a plateau, that plateau is far below total exertion.

In summary, the data suggest that 30 foot ramps, particularly those at slopes of 1:12 and higher, present some difficulty for manual wheelchair users, but not people who use other types of mobility aids. However, with the exception of a few older, female subjects, a surprisingly high percentage of manual wheelchair users were able to traverse fairly steep ramps (75% at 1:8), and to did so without expending energy at risky levels. This suggests that when other variables that could impact ramp use (e.g. side slope, lengthwise slope, surface texture and environmental conditions) are controlled, the 1:12 maximum slope currently allowed by access codes seems to be acceptable for a 30 foot distance and that ramps steeper than 1:12 might be acceptable if there were shorter distances between level landings.

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DEVELOPMENT OF A UNIVERSAL DISABILITY INFRARED LINK PROTOCOL STANDARD

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Abstract

Public information systems and appliances are increasingly being designed to include features to allow them to be used directly by people with disabilities. However, we do not know at present how to design such systems so that they can be accessed by everyone, especially those with severe or multiple disabilities where use of a personal assistive device might be required. One mechanism for allowing these individuals to access public information appliances would be to include a low-cost infrared link as a part of the devices' design. Users could then interface with the device using their own interface – braille display, etc. – on their personal assistive technology. A standard interaction protocol for such an infrared link is under development as a cooperative project with participants in both the U.S. and abroad. The protocol is based upon a small number of robust commands intended to be used in conjunction with the IrDA infrared standard. The protocol is suitable for both public and home systems/ appliances. An initial implementation on a touchscreen kiosk has been carried out. Plans for incorporation in assistive technology devices are underway.

Background/Statement of the Problem

Once limited to ATMs, which allowed individuals access to basic banking services around the clock, the information appliance industry has grown to include everything from touch screen telephones to building and airport information kiosks. Increasingly, individuals with disabilities have access concerns as our society becomes more dependent on the use of these types of electronic appliances. However, if some universal design concepts are applied in the development of these systems, perhaps a greater percentage of the population will want to and also be able to utilize these systems.

For example, an individual who was blind could use a separate device (e.g., personal computer with voice or Braille) to access the information appliance provided they could communicate with it. They would be able to find out what was on screen at any point in time (text and buttons or controls). They could have that information displayed for them on their remote device and activate the controls, also from their remote device.

Another example might be an individual with a physical disability who was unable to reach or use the standard controls (e.g., someone with high spinal cord injury who used sip and puff controlled wheelchair). This individual could view the information on the regular screen of the electronic appliance or their personal assistive device, and use the assistive device to activate the buttons or controls.

The simple addition of an infrared port on the electronic appliance would allow individuals with visual and physical disabilities to both locate and interact with the electronic information appliance. However, without a standard protocol or interaction language, it is unlikely that such infrared ports would be deployed or used.

Rationale:

The Universal Disability IR Communication Link is intended to be used with a number of electronic appliances that have already begun to appear in the market place. These include:

ATMs
Information Kiosks
Building Directories
TV Set Top Boxes
Bus Stops (Electronic Interactive)
Fare Machines (ticket machines, etc.)
Home Appliances (especially touchscreens)
Informational Telephones, Screen Based Telephones
POS, point-of-sale
Home Environmental Control and Security
Whiteboard, classroom and interactive systems
Games and Entertainment

done. (no return between so they would appear on the same line of the user's display.

Details on the description table sent in response to LIST command:

- Each information or action item "on the screen" has one line in the table describing it.
- Each line would consist of the following pieces of information for an item. These pieces of information would be separated by tabs: (fields 4 and 5 may be optional)
    1) reference number for the item (e.g., #2)
    2) verbal name for the item (e.g., "Main Menu")
    3) value (e.g., whether a checkbox was set or not)
    4) type or description (e.g., button, scrolling field etc.)
    5) position (e.g., bottom right of screen,
- The first line in the table would always represent a "virtual" item on the screen which would provide information about the current screen (or context). The line itself would contain the name of the screen (or context).
- In addition, activating this first item (first line) would cause information about the current screen to be sent to the user. Activating this item (line) successively would cause more information to be given as follows:
    - 1st activation: where the user is
    - 2nd activation: the function of this screen (context)
    - 3rd activation: the choices available here
    - 4th activation: description of the layout of the items on screen
    - 5th activation: graphic description of the screen or context

Security

In order to ensure that the infrared interactions are secure or private, appropriate security measures need to be taken. One approach being explored is based on the PGP two-key system. Basically, it would work like this. Only those portions of the interaction which are confidential would be encoded. Predictable or known sequences of commands would not be encoded. When it came to entering the user's PIN number, for example, the kiosk would generate a PGP code pair and pass the key to the assistive technology. The assistive technology would use that key to pass the user key (which it would generate) back to the kiosk. The user would then transmit their PIN number in encoded fashion to the kiosk. Immediately on receipt of the PIN number, both codes would be discarded and any future communications would occur using a new code key pair.

Evaluation/Discussion

The current "straw man" protocol presented here is the result of information and input to the project from both industry and consumers via a listserv and through special open working sessions at CSUN, RESNA, and Closing the Gap conferences. An early version of the protocol was also implemented on a touchscreen kiosk prototype. An infrared adaptor was then attached to the serial port of a Braille Lite (a portable, notebook sized assistive device with 18-cell braille display) and used by an individual who is blind to control and use the kiosk using only the braille display on the Braille Lite. Plans are currently underway to have the small routine to support the infrared protocol built directly into a next-generation Braille Lite product.

An evening working session on the IR protocol is planned for the 1996 RESNA conference.

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Design

The Universal Disability IR Communication Project has several design objectives and requirements. The objectives are as follows:

- To develop a bi-directional universal disability infrared link whereby individuals with different disabilities equipped with specialized access devices could both locate and interact with various electronic information systems.
- To develop guidelines or a "standard protocol" for this universal disability IR link, building upon accepted industry standards, such as the Infrared Data Association (IrDA).
- To advocate and work closely with product developers to get the ideas and "standard protocol" for this universal disability IR link incorporated into as wide a variety of main stream electronic devices as possible.

To meet these objectives, the Universal Disability IR Communication Link will also require the following:

The link must always be looking for a connection (so that the person with a disability can approach a system and have the system recognize them without requiring the person to activate the link from the system. We may need to utilize other wireless technologies [e.g., RF] to assist individuals using the IR link in navigation to and/or location of "targets"

- There should be some type of security provided
- The link should not interfere with other IR uses.
- The link should not be blocked by other IR uses.
- The link must be bi-directional.
- The link should support talking sign technologies (either directly or by allowing the talking sign technologies to exist side-by-side on the same device so it can be located by a user who is blind).
- The user should always be considered in control of the link. (The user makes a request via the link, and the system then responds via the link. The system may respond with a choice for the user to make, but it is still the user in control.)

Development

A first draft or "strawman" protocol for the Universal Disability IR Communication Link is being proposed as follows:

PART I: Protocol for communication from the "aid" to the "information device". There are three commands that can be sent by an assistive device (e.g., aid):

NAME	COMMAND	DESCRIPTION OF COMMAND
RESET	#R <ret>	reset system to start (local home)
LIST	#L <ret>	send a list of information and action items
ACTIVATE	**#item reference number <ret>** or **verbal name of item <ret>** to activate this item	

(Note: When the user sends the "list" command, the device may optionally display the names or reference numbers next to the items on the screen to facilitate access by users who can see the screen but who must use an alternate device connected via the IR-link to "push" the buttons etc.)

PART II: Protocol for communication from the "information device" to the "aid". All information sent by the "information device or electronic appliance" is in response to commands from the user (e.g., aid).

In response to **RESET**: The device sends "reset received" and then "done," along with any text necessary to reflect a change of context to the user (e.g., the when the kiosk is busy or the screen changes to a new screen) when done.

In response to **LIST**: The device sends a tab delimited table listing all items currently displayed and "accessible" for reading or action. Each information or action item has one line in the table describing it.

In response to **ACTIVATE**: The device would send "<name of item> received" and then "done" when

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Cognitive Disabilities & Technology

INITIAL ASSESSMENT OF INDIVIDUALS WITH SEVERE COGNITIVE DISABILITIES FOR AUGMENTATIVE COMMUNICATION

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Abstract

Evaluation of the potential for improving the quality of life of individuals with severe cognitive disabilities through assistive technology requires an ecological perspective. One task of the evaluator is to gain some understanding of the contributions of cognitive, motor, psychiatric and situational factors to the individual's current style of functioning, in order to assess the potential for change and determine whether modifications may be necessary in other aspects of the individual's care. Another task is to coordinate with other providers of service to this individual in order to address the needs of the whole person. The decision to institute a new way of interacting with others is one in which the person with disability would ordinarily be expected to participate. Before imposing a change on someone whose cognitive disabilities make it difficult for him or her to participate in the decision, the evaluator needs to assess its ecological impact. Some guidelines for making this assessment are offered, and illustrated by examples.

Introduction

The diagnosis of severe mental retardation is rarely, if ever, unique. Neurological involvement extensive enough to produce global severe cognitive deficits usually affects other body systems as well. On a functional level, the interaction of the deficits resulting from the primary impairments often gives rise to secondary deficits. For example, the atypical social behavior of children and adults with autism elicits atypical social and language response on the part of persons who interact with them, including parents and research investigators, among others (1,2). Disabilities tend to be unfortunately synergistic, and, conversely, it is rare that functional outcomes can be directly and uniquely attributed to single underlying causes.

At the same time, evidence of severe motor or psychiatric deficits in the presence of a diagnosis of severe or profound mental retardation should be treated as a red flag. It is possible, and frequently the case, that someone with severe motor disability is classified as having severe retardation because of assumptions about the relation of motor ability to cognition, or overly concrete interpretation of developmental level scores on unadapted tests. This is more often the case with older individuals but may also be encountered in school-aged children.

The augmentative communication evaluator has the opportunity and responsibility to attempt to untangle these factors, in order to estimate how changes in communication or in other aspects of the individual's function might nudge the person's interactive style in the direction of greater enrichment and control. Following are some informal guidelines for carrying out this assessment:

Observe

The first component of evaluation at this stage is observation of whether and how the individual interacts in typical unstructured settings. Does she initiate and maintain interaction? Is she actively avoiding social interaction or oblivious to it? Is this a typical day or a bad day? Is this the individual at her social best, with the people she prefers?

Listen to the individual's vocalizations, if there are any, and note the circumstances under which they occur and the effects they have on others. In a behavioral sense, the effect they have is their meaning. If others disregard the vocalization, or repeat parts of it in an "in quotes" manner, the speech is not functional, and the phrases are probably stereotypies. Continuous chanting which rises to a higher pitch and increases in volume when others approach or try to interact serves to keep people at bay and maintain social separation. In contrast, screaming may have the behavioral effect of bringing people over to see what is wrong. It may also deter family and others from taking this person on outings in the community, an effect which may or may not be part of the individual's intention.

Attend to the individual's history

Both the written records and conversations with people who know the individual well are invaluable in assessing the potential for improving quality of life with augmentative communication. There may be information in the records which will provide clues to latent abilities, such as former communication modalities; undeveloped interests which could provide motivation (e.g., the information that the individual used to have a pet), or to the presence of modifiable barriers, such as an indication that glasses used to be worn.

It is also important to interview the persons who know and are fond of the individual. Your task will be easier and more likely to be successful if the person who knows your client feels a personal, respectful commitment to him.

An example: Mr. K. was reported to display challenging behavior, including hitting and pinching whenever he was transferred in the standard way between bed and wheelchair. This was regarded as part of his behavior, and persons dealing with him took care to move quickly out of range. In contrast, a care provider who knew him well and would enlist his help in making transfers, and allow him as much control as possible in the manner and pace of transferring reported minimal occurrence of this behavior.

Review of the medical chart and questions to one of the physicians indicated that Mr. K. may have a condition which causes him discomfort when he is moved. Unfortunately the terminology used to describe the condition is unfamiliar to non-physicians. By bridging the communication gap, the augmentative evaluators were able to promote a positive change in this person's quality of life and influence how others perceive his behavior. This example is interesting also in regard to the pragmatics of communication. This gentleman can use speech functionally, and yet did not make clear to his care people that he was experiencing discomfort. One possible interpretation is that he was not accustomed to using words for body parts or the expression of discomfort. Interview of someone who knew him well, however, included quotes of verbal reports of pain in the course of a non-routine activity. This gentleman may have perceived that others knew quite well that he was having discomfort, since some of the time he was transferred in a different manner, without this discomfort, and since he complained by vocalizing loudly and hitting. Like many of us he was exasperated by others' not recognizing the displeasure which to him was entirely obvious. Rather than interpreting the problem as a lack of communicative means, and devising and training this individual in an augmentative technique for doing so, an intervention was chosen which augmented communication among care providers.

Involve yourself

How we describe interaction is inevitably filtered through their assumptions and theories. If you have concerns about the presence of intentional communication, despite reports by others, you won't really be confident unless you experience it. The standard assessment tricks, such as interrupting a preferred activity, or slowing it down, to see whether the individual will act to make the activity resume or speed up; or displaying a favorite object or edible, to see whether the person will act to acquire it, are useful. There is usually not a role at this stage for an adapted response mode. It's not the success of the communication but the presence of intent that you are trying to determine, and that will in turn determine your decision regarding use and type of augmentative technique. It is almost a tenet of our faith in assistive technology that if there is need and motivation, suitable transducers can be identified and their use trained, whatever the constraints. Assessment with adapted transducers over time is a subsequent, usually much lengthier process.

Involve yourself in other aspects of the problem. Do cross disciplinary lines. Talk to the seating specialist about the individual's prospects for more functional positioning, or the recreational therapist about novel meaningful recreational activities. You will not know whether there are possibilities for doing things differently unless you voice your questions, concerns and ideas and discuss them with people who have the knowledge you lack.

Conversely, coming from a background of experience with assistive technology, you bring a perspective which you may take for granted but which professionals from different backgrounds may lack. You need to communicate your perspective to them so that they can consider the issues in the light of how the individual's communicative function could be augmented. Like disabilities, interventions can be synergistic, but only if they are coordinated and integrated, not only in their implementation, but in their conceptualization.

An example which has parallels to assistive technology is the area of psychiatric disorders and the use of psychotropic medication. Medication can play an important role in the lives of these individuals, for good or ill, and persons working with this population need to have at least an informed consumer's level of knowledge (e.g., 3). In general, most people are aware of the dangers of neuroleptics. A recent review of self-injurious behavior (SIB), which is found in a high proportion of persons with severe retardation, came to the conclusion that SIB is best characterized as compulsive behavior (4). This is of interest since it raises the question of whether medications which have begun to be used to very positive effect with obsessive compulsive behavior in the general population of persons with psychiatric disorders may have some benefit to offer to persons with severe retardation. We find ourselves having to educate the public that people with apparently insurmountable motor and cognitive challenges can and do communicate effectively, and have the potential to lead more rewarding lives than used to be imagined. Similarly, new developments in biological psychiatry have begun to make it possible for some persons previously incapacitated by certain types of symptoms to lead fulfilling lives. We are in the unaccustomed position of needing to have our consciousness raised regarding the possibilities now open to persons with disabilities of neuropsychiatric origin.

Describe specifically

When you are reading through the individual's history, the most useful information you can find is in descriptions of behavior in context. If the history included hypertext connections to video records which let you see how the person behaved under various circumstances, it would be even more useful. In the meantime, the best service you can provide for others who will review these records and for yourself when you follow up to assess whether change has occurred, is to provide a rich picture of the person's typical communicative behavior, including affect and manner.

Summary

The guidelines discussed above exclude use of developmental tests which yield numbers in terms of months or years of mental age. Also excluded are formal assessments of language comprehension. Observation, interview of those who know the individual best, and interactions in which you engage are much more informative and pertinent to assessing potential for use of augmentative communication.

The evaluation discussed here is the stage preceding evaluation of motor control. The outcome of this evaluation will be as rounded as possible a picture of the person's communicative function in his context, and the determination of whether there are unmet communicative needs. The presence of intent and involvement which exceed expression; the existence of situations which are frustrating for lack of a means of expression; communicative attempts which are being misinterpreted or dropped; or misinterpretation on the individual's part of the communication and behavior of others, are all indications that augmentative communication may have a role to play. In the absence of any mismatch of this type, the next question is whether there may be the potential for expansion of the person's sphere of activity and interaction. The means of provoking growth may be communicative intervention, including augmentative devices or pragmatics instruction, or it may be a matter of intervening with training and support for direct care staff. Alternatively, it may be an intervention in another domain. It may take evaluation of seating to determine whether more upright posture can be achieved, and visual assessment to determine the need for glasses, or use of communication techniques that do not require upright posture or visual contact or it may take adjustment of medication so that the individual is awake during the day, or so that his time is not totally consumed with obsessive activities, or changes in staffing so that someone is available to play basketball when the individual requests it, before communication options can be developed.

By attending to the ecology of the person with severe disability, the evaluator maintains the appropriate perspective: ask not whether the individual can do augmentative communication, ask whether and in what ways augmentative communication, in interaction with adaptation of other aspects of the human and physical environment, could contribute to the quality of life for this individual.

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SELF-CATHETERIZATION AIDS FOR DISABLED FEMALES

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ABSTRACT

Loss of hand or arm function prevents certain female clients from performing intermittent urinary catheterization. Devices that will help hold and position the catheter relative to the "target" or uretheral orifice are needed.

This same or a companion device must assist in spreading and holding the labia to expose the orifice and make it available for insertion of the catheter. A free-standing or leg-supported mirror is used by the client to view the orifice.

This facility has designed such assist devices which have been tried by two disabled clients. This has improved ability to position and handle the catheters; however, neither client has developed enough skill or confidence to use them on a functional basis.

BACKGROUND

Inability to perform intermittent self-catheterization deprives many disabled women of privacy and independence. They must rely upon help of others or yield to installation of indwelling catheters which are inconvenient and are sources of infection. Some of these clients may be able to perform self catheterization if a device that will hold and guide the catheter is provided. Even though no device that accommodates all clients and situations has been developed, some progress has been made. Hopefully, other developers will benefit from the efforts described herein.

OBJECTIVE

The objective was to design and fabricate aids that would enable female clients with limited hand function to perform intermittent self-catheterization.

APPROACH

This facility designed several assist devices which help spread and hold the labia and direct the catheter toward the uretheral orifice (see Figure 1). The labia holder and catheter guide was made from thin, transparent, heat formable plastic material. A jig was made of heavier plastic sheet material which is easily modified. The plastic sheet is heated with an electric heat gun and then molded around the jig.

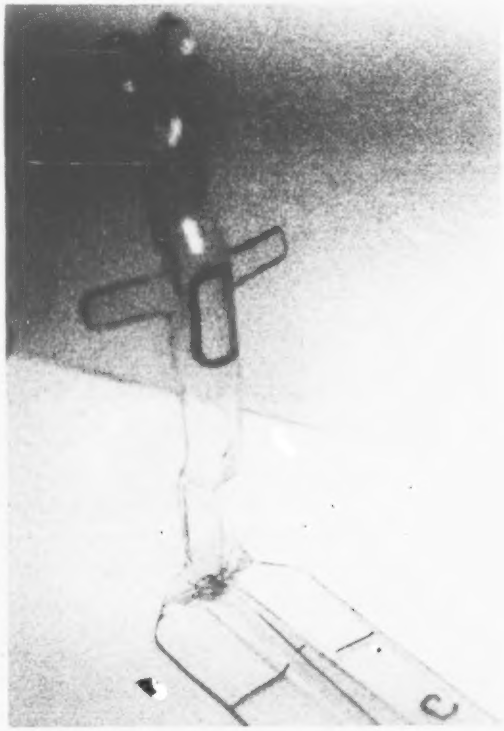

Figure 1. Labia holder and catheter guide and holder.

Since anatomy of external genitalia varies in females, the patient is examined by a nurse with extensive experience. The nurse and engineer collaborate on design configuration for the catheterization aid. The vertical dimension from the buttocks, when the patient is supine, to the uretheral orifice is critical (see Figure 2). The shape of the body of the transparent aid is important because it must hold the labia majus apart to expose the "target" to the view of the client. The examining nurse also provides specifications regarding shape and size of the labia spreader-holder part of the fixture. Another purpose of the fixture is to retain position of the catheter any time the user releases her grip.

The catheter is threaded into a small hole in the fixture. This friction fit helps the user control penetration rate and keeps the catheter in position even if it slips from the hand. Alternately, a larger window can be used if the client has good hand function and good vision. The base of the assist device is stabilized by slipping it under the buttocks of the user. A "blank" or unfinished fixture is provided to the nursing staff who mark it so that a catheter insertion or guide hole can be machined into the fixture.

One candidate was a twenty-five year old woman who was one year post traumatic injury. She had multiple bone fractures and amputation of her non-dominant left arm below the elbow. She was somewhat overweight and her trunk range of motion was restricted by a body cast. She drove a powered wheelchair with her dominant right hand. She wished to achieve a measure of independence by developing the ability to perform intermittent self-catheterization. Because she had limited range and short arms, she was unable to successfully perform self-catheterization.

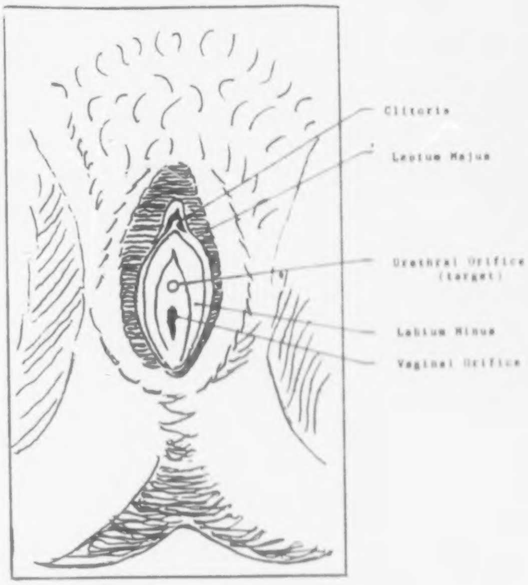

Figure 2. Female Genitalia

Similarly, another client had both hands, but was weak and had poor dexterity. The assist device was helpful but the head-injured client never developed the capability to perform self-catheterization on an entirely independent basis. Cognition was a factor.

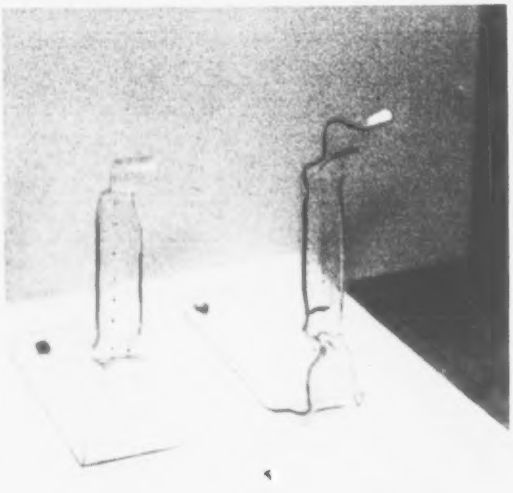

Figure 3. Fixtures must be custom fabricated to accommodate anatomy and capability of user.

DISCUSSION

Self-catheterization by disabled females, such as those suffering from neuromuscular disorders or traumatic injury, is an important but very difficult goal. First, it is difficult to acquire clients who are willing to participate in a development program. Second, adequate assist devices or technical expertise for designing them, are not ordinarily available. Third, it is difficult to acquire reimbursement for this effort. The interest and participation of other rehabilitation facilities and staff members toward the solution of this task is encouraged.

CONCLUSION

Many disabled females would be much more independent and employable if they could perform intermittent urinary catheterization. Partially successful results have been achieved at this facility through modest development efforts. Other innovators and developers are encouraged to address this difficult and very significant problem.

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ACKNOWLEDGEMENTS

The nursing and technical support staff of this facility have worked on development of catheterization assist devices on an "off-the-record", non-reimbursed basis. Cerca 1986, a labia spreader-holder was fabricated and successfully used by an inpatient with limited use of one hand and arm. Cerca 1987, a knee-held mirror, was developed. Cerca 1991, a catheter guide was made for an inpatient with limited hand function. Results of these efforts were not published because limited success was achieved. Nevertheless, this staff recognized the need for catheterization aids and has developed partially successful devices. Frustration abounds because resources are not available for a concentrated attack on this problem.

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Paralyzed Veterans of America (PVA) Student Design Competition

1996 PVA Student Design Competition
Project Submissions

***The HSO (High Stability Omni) Wheelchair**
Kurt Kornbluth, San Francisco State University

Battery Powered Play Vehicle Steering System for Motion Disabled Children
Cesar Echevarria, Nelson Garcia, Juan Rivera, Arsenio Sanchez, University of Puerto Rico

Multifunctional Direct Access Memory Voice Recorder
Luis Montoya, Illinois Institute of Technology

***Helping Hands Child Resistant Safety Cap and Bottle**
Steve Daniels, Milwaukee Institute of Art & Design

***Quality of Life Improvement with Vibrations**
Jeffery Norrell, Ana Maria Castano, Robert Stone, Dennis Chapman, University of Texas @ Austin

Design of a Universal Switch Mount
Aaron Little, Kamel Saidi, Joan-Marie Shouman, University of Texas @ Austin

Batter Up! Assistive Technology for the Sports Enthusiast
Anthony Yannitell, Greg Faulkner, Khaled Jafar, Mary Rychlik, University of Texas @ Austin

Design of an Assistive Communication Device for Individuals with Cognitive and Physical Disabilities
Edward Bezdek, Jennifer O'Toole, Scot Gallaher, Judy Liu, University of Texas @ Austin

Recycling for the 22nd Century
Altaf Arsiwala, Gilbert Garduno, Neal Lipman, University of Texas @ Austin

Digital Logic Controlled Electromechanical Long Leg Brace
Steven Irby, Kenton Kaufman, David Sutherland, San Diego State University

Assistive Trunk Loading Wheelchair Lift
Michael Leitzinger, Jeffrey Drinkard, University of Alabama

Design of a Hand Extension Exerciser
W Mark Richter, David Eveland, Delia Sauceda, Santa Clara University

****The Development of an Extendable Below-Knee Pediatric Prosthesis**
Randy Bernard, University of Pittsburgh

***Bus Stop Locator: An Application of Audible Signage Technology**
Stephen Tippin, Donna Therrien, Chris Gorff, Steve Belcher, Wright State University

Pediatric Therapeutic Playstation
Michaela Wiegel, Case Western Reserve University

System for Controlling Shocks and Vibrations on a Wheelchair
Abimael Alvarez Torres, Diaz Otoniel, Manuel Birriel, Robert Rivera, University of Puerto Rico

Design of a Transfer Device for People in Electric Wheelchairs
Harry Montanez, Carlos Pantoja, Jaime Cintrom, Willfredo Rios, University of Puerto Rico

***Occupational Rehabilitation Center**
William Todd Martin, C Tucker Cope, Matthew Morrison, Zafhair Hadi, Case Western Reserve University

*Winning Projects; **Honorable Mention Project

Paralyzed Veterans of America (PVA) Student Design Competition

Well, we've finally succeeded in the goal I've had since taking over as Chair of this project; that of honoring each of the Student Design entrants with publication! Thanks to some major changes made by the Awards Committee, SIG Reviewers, and most importantly, having entries to meet a much earlier submission deadline, WE HAVE DONE IT!

For the first time, you will be able to read every Student Design paper, which made it through the SIG reviews. To me, this is very pleasing. To all of the hard working students, it represents at least, the feeling of importance. As I have argued in the past, "It is the very least that we should do, particularly knowing that there's someone out there, who could benefit from this research."

Although you will only be meeting the top 5 winning project authors in person, you will still be able to learn from all of the rest. Please feel free to contact the other Student Design authors, should you need additional information.

What else can I say? With PVA as our new partner in this venture, I'm sure you will agree that we now have a real *Class Act* in our Student Design competition. PVA's reputation as a springboard or catalyst for great technology interventions, is now proven. Please help us express our gratitude for their tremendous support of this project. Enjoy the technology. It is yours for the taking as we explore these new horizons.

David F. Law, Jr.
PVA Student Design Competition Chair

THE HSO (HIGH STABILITY OMNI) WHEELCHAIR

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ABSTRACT

Wheelchair stability is a major issue for wheelchair riders and designers. Historically, short wheelbase and high center of gravity have made wheelchairs inherently unstable and prone to tipping forward and backward. The HSO-Chair (High Stability Omni-wheel) wheelchair combines a modern version of the Ezikiel Omnidirectional wheel with a new frame design and specially designed rear anti tip wheels. Static and dynamic stability tests have shown the HSO-Chair to have a dramatic increase in stability without an increase in overall length or reduction in maneuverability.

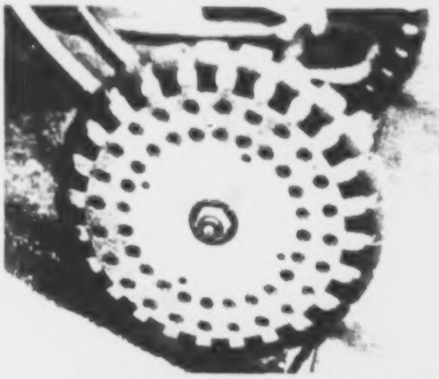
BACKGROUND

A recent rider survey funded by the Centers for Disease Control (1) showed that the majority of injuries experienced by wheelchair riders were a result of tips and falls due to stability problems inherent in modern compact wheelchair designs.

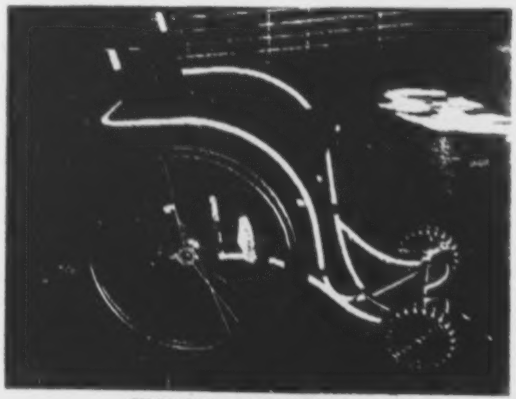
Currently, in the commercial market, a design compromise is made between wheelchair wheelbase and caster size, and stability. In order to make a conventional wheelchair small enough to be used conveniently indoors, the wheelbase has been shortened so much that the chair can easily tip forward, especially when impacting obstacles.

In conventional wheelchairs, the front casters are placed behind the rider's feet to allow the rider to have a comfortable riding position, with knees at 100 degrees or more, while allowing the front casters to swivel. There is also a design tradeoff between front caster size and stability. By using smaller caster wheels which require less space to swivel, chairs are made more compact. Chairs with these small casters, however, are easily upset by small obstacles such as cracks in sidewalks. Wheelchairs can be made more stable by lengthening the wheelbase using larger size caster wheels, however, lengthening the wheelchair reduces accessibility, especially indoors.

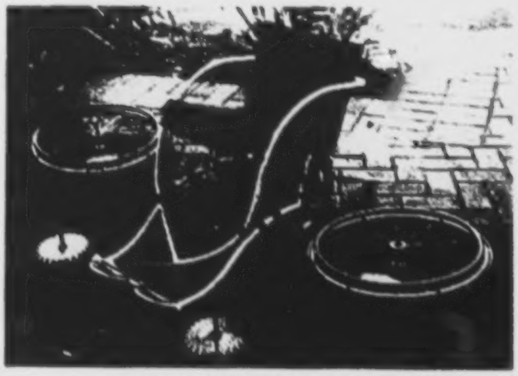
One way to meet both accessibility and stability requirements for wheelchairs is to replace the front caster wheels with the Ezekiel type of omnidirectional wheels. The Ezekiel Omnidirectional wheel (under development for



THE OMNIDIRECTIONAL WHEEL



THE HSO-WHEELCHAIR



THE CHAIR BROKEN DOWN

BEST COPY AVAILABLE

wheelchair use for more than 20 years, but still not without some shortcomings) rolls backwards and forward as with a conventional wheel, but also rolls sideways with the help of rollers mounted along the circumference of the wheel. (see photo). Thus, with omnidirectional wheels in place of standard front casters, the front wheels do not have to swivel (can be fixed in position) to enable he wheelchair to steer. Fixed front caster wheels open up new possibilities for increasing wheelchair stability such as:

-Using larger diameter caster wheels without increasing overall chair length.
-Significantly increasing wheelbase without increasing overall chair length.
-Positioning caster wheels alongside or forward of the footrests, reducing the tendency of the footrests to impact obstacles and cause forward tipping.

DESIGN OBJECTIVE AND CRITERIA

My objective was to design and build a prototype manual wheelchair taking full advantage of the enhanced stability and accessibility characteristics possible with omnidirectional wheels. The chair was to be a simple, lightweight, design, with rider positioning, steering characteristics, and overall dimensions within accepted modern wheelchair standards.

Design requirements

-Rider positioning, comfort, handling and steering characteristics equal to or exceeding present industry standards.
-Rear axle adjustment for camber, width, height, and wheelbase (to suit different riders and disabilities).
-Non-folding design (for simplicity).
-Front suspension (to provide some flexibility with rigid frame design).
-Lighter than 30 lb.
-Easily broken down for convenient transport (quick release wheels, front and rear).
-Use of off-the-shelf parts and materials wherever possible (to reduce time and cost of prototyping).
-Inexpensive to prototype (buildable in steel or chrome moly, etc.).

APPROACH

An iterative design approach relying, heavily on iterative cycles of prototyping and evaluation rather than analysis was used. This method was used because of the relative ease and low cost of prototyping, and complexity of analysis.

METHODS

The latest version of the Omnidirectional wheel designed for wheelchair use was obtained (see photo). This wheel was developed by La Fever and associates of Berkely, CA, under the supervision of Mr. Robert Krolick. Initial testing was done and it was determined that the steering, rolling, and durability characteristics of this wheel were suitable for the project. Next, "test bucks", commercial chairs fitted with these omnidirectional front wheels in place of their casters, were assembled. These wheelchairs incorporated variable seat height and recline, chair center of gravity, and front and rear wheel placement. The test bucks were used to optimize front and rear wheel position and track (width between wheels), as well as rider position and wheelchair center of gravity, for wheelchair stability, maneuverability and comfort.

Testing included quantitative static and dynamic stability tests as well as subjective tests incorporating climbing, and descending of stairs and curbs. Testing was performed by both disabled and non-disabled riders Wheelchair rider test clinics were also held for evaluation and comparison of different wheelchair geometries.

After the basic wheelchair geometry was established, different frame designs (on paper and models) were produced, reviewed and discussed with wheelchair riders and other designers. A first prototype was built and tested in a manner similar to the initial test bucks. This time front suspension and frame flexibility were also tested. This provided the basis for the second, final prototype seen in the accompanying photo.

FINAL PROTOTYPE - DESCRIPTION

The final prototype is 39 inches long (without anti tip wheels) with a wheelbase adjustable from 22 to 26 inches. The seat to back is 90 degrees and the seat is reclined 15 degrees. The frame is composed of 10 pieces of 3/4" mild steel tubing (1.2 mm wall thickness) with brazed joints, and weighs 29 lb. It incorporates an off-the-shelf rear axle carrier that is adjustable fore and aft as well as for camber. The frame is non-folding but both front and rear wheels are of the quick release type for easy disassembly during transport. The frame is rigid but the front section is composed of crossing tubes not attached in the center. This allows the front of the frame to twist like a spring, while the rear section is quite rigid. The front wheels are mounted to a single axle tube that is a structural member of the frame. The sling seat is made of Cordura nylon canvas. The foot rests are semi circular tube with elastic webbing to support the riders' heels .

The prototype was also fitted with removable rear anti tip bars made of spring steel with small castered wheels at the rear. These allow the chair to be ridden with the rear axle in the forward position without the danger of the rider flipping backwards. This near center of gravity position reduces the weight on the front wheels making the wheelchair easier to steer and have less tendency to steer downhill on sideslopes.

TESTING

The final prototype was tested according to ANSI/RESNA/ISO standards (2) for static stability. The prototype was also tested comparatively, against a variety of other production wheelchairs, for dynamic stability (riding over variable height obstacle at 3 and 6 mph). All stability tests were done without rear anti-tip wheels.

Test clinics were also held for disabled riders to evaluate design, stability, comfort, and maneuverability of the HSO-Chair

TEST RESULTS/ / RIDER FEEDBACK

The static stability test (see table) showed a forward tip angle of 39 degrees (versus maximum of 28 degrees for other production wheelchairs tested) and back tip angle of 11 degrees (within the range of other production wheelchairs tested).

The dynamic stability test (see table) showed the HSO-Chair cleared obstacles 3/4" higher (at 6 mph), and 1/2" higher (at 3 mph) than any of the other six current production chairs tested. The HSO-Chair was able to clear a 2 1/2" obstacle without throwing the rider

* It should be noted that although this is not intended as a durability test, some of the test chairs fail structurally from the repeated impacts. The HSO-Chair received no structural damage during any of the testing.

CHAIR*	STATIC		DYNAMIC	
	Tip angle(deg.)		Obstacle ht. (in.)	
	back	front	3 mph	6 mph
HSO-C	11	39	2.25"	2.5"
Hosp(S)	12	19	.75	1
Breezy(P)	10	24	1.5	1.75
QD1(P)	9	24	1.25	1.5
Whirl(Z)	11	18	1.0	1.25

*Hosp(S) -Hospital style folding chair
*Breezy(P) -Quickie Breezy folding chair
*QD1(P) -Quickie rigid chair
*Whirl(Z) -WMC Whirlwind II chair

Rider feedback was very positive. Inexperienced riders were able to descend curbs and low stairs at low or moderate speeds with full stability and confidence. Riders felt the compliant front suspension walk over uneven ground, keeping all four wheels on the ground. They also found the rear tip wheels effective in preventing rearward tips. The anti-tip wheels also permitted the rider to easily achieve a "wheelie" position to ascend curbs and avoid obstacles. During the tests, some wheelchair riders expressed interest in purchasing the HSO-chair, if it were for sale.

On the minus side, noticeable vibration could be felt from the omnidirectional wheels rolling over hard, smooth pavement. Friction in the rollers of these wheels also made it harder for riders to turn the chair, especially at higher speeds. Some sports chair riders found the chair too long for indoors

DISCUSSION / CONCLUSIONS

There is a need to improve wheelchair stability to reduce rider injuries and increase their independence. The HSO-Chair prototype proves that wheelchair stability can be improved dramatically with little sacrifice in size, weight or maneuverability. Using the omnidirectional wheels in place of conventional casters, wheelchair riders' access, comfort, confidence and safety levels can be improved immediately. Improvements in the smoothness and lateral rolling resistance of the omnidirectional wheel are needed, however, before these advantages can be realized. It would be worthwhile to develop both the Chair and omnidirectional wheel in parallel with the goal of eventual commercialization.

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ACKNOWLEDGMENTS

Special thanks to Mohammad Abu Shalbak, and Khaled Omar Daoudi for their design ideas and help in the construction of the prototypes. The author also wishes to thank Peter Pfaelzer, Ralf Hotchkiss, and Ronald Gaal of the Wheeled Mobility Center at San Francisco State University for their guidance and support, and all test clinic volunteers for their input and ideas.

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HELPING HANDS CHILD RESISTANT SAFETY CAP AND BOTTLE

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ABSTRACT

The elderly and those afflicted with arthritis often find it difficult to use Child Resistant Safety Caps (CRSC) on prescription medicine bottles. These individuals are greatly challenged by this situation and are inclined to circumvent the protection CRSCs offer, thus placing young children at risk of accidental poisoning. On June 15, 1995 the Consumer Product Safety Commission revised the Poison Prevention Packaging Act of 1970 by implementing performance standards for CRSCs (1). This CRSC and bottle system is designed to meet these performance standards.

BACKGROUND

On June 15, 1995 the Consumer Product Safety Commission put into place performance standards for CRSCs. Industry has until December 1997 to bring to market new CRSCs that meet this new standard. The new regulation requires all CRSCs to be tested by two panels. One panel consists of one hundred children four years of age or younger. These children will be given the product and allowed ten minutes in which to attempt to open it. If twenty percent or more of the children succeed the product fails. The other panel is made up of adults aged 50 to 70. The adults are given five minutes in which to open the product, and then one more minute in which to close and open the product once more. If ninety percent or more of the adults cannot accomplish this the product fails.
Negative commentary of present CRSCs come from organizations such as the American Academy of Pediatrics. It states that 60% of the elderly can not open most examples of present CRSCs, and will commonly transfer medications to bowls or other unprotected containers (2). Further more the Poison Control Centers in America receive more than one million telephone calls yearly from parents whose children may have ingested medicines or chemicals. In 1993 130,00 children were admitted to emergency rooms for accidental poisoning, of that number 20% were attributed to poisoning by their grand parents medication. And finally of that number, 50 of those children died.

PROBLEM STATEMENT

The objective is to design a child proof safety cap or packaging system that relies on cognitive ability rather than physical ability to open.

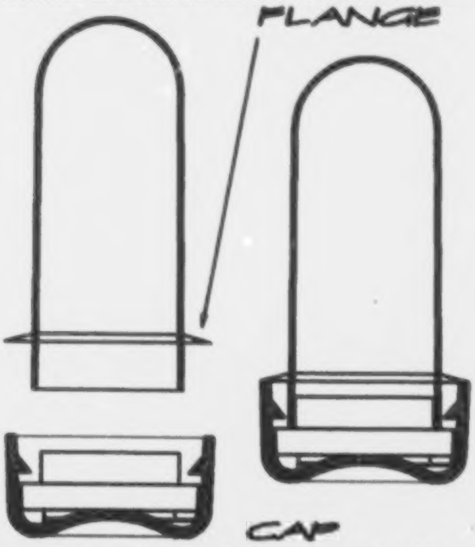
RATIONALE

The failure of present day CRSCs is not that they are not child proof, but rather that they are daunting to use by the physically challenged and indeed many "normal" adults. Adults who are challenged by the present CRSCs tend to circumvent the child proof features of the packaging for their own convenience. If a new design were less physically demanding to use it is possible that adults would be less inclined to defeat any safety features.

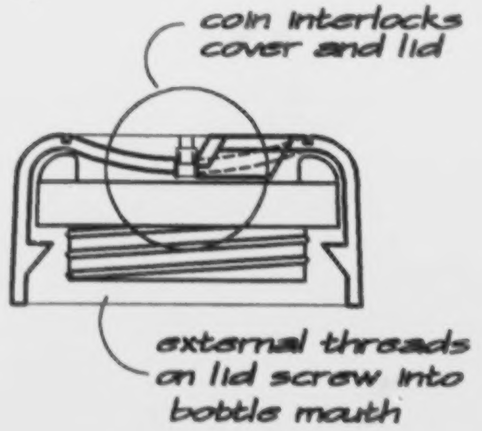
DESIGN

The Helping Hand Cap and Bottle are inverted from the conventional orientation. The cap is of a substantial diameter for ease of grasping and it also serves as a sturdy base that is tip resistant. The bottle is tapered to present a clean line for grasping the bottle off of crowded shelf condition and also to add draft for manufacturing. The top of the bottle is rounded to prevent the open bottle from being stored on a shelf without the protective cap in place. The angled flange on the bottle above the cap is a shield against dripping water, dirt and the grasping fingers of young child who may try to pull the cap off.
The cap and bottle are made of injection molded plastic. The cap consists of two pieces, a lid and a cover. The lid snap fits into the cover and is retained

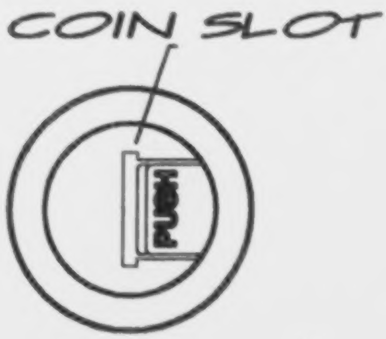
by an aggressive boss for permanent installation. The cover free wheels around the lid in the counter clockwise direction for it's child resistant feature.



Rotated clockwise, lugs in the cover mesh with bosses molded into the lid, threading the lid into the bottle. The lid has external threads while the bottle mouth has internal threads.


coin interlocks cover and lid
external threads on lid screw into bottle mouth

Opening the cap is by two means. One method which is designed for the physically challenged is accomplished by dropping a coin into the slot in the cover. The slot will accept a penny, nickel, dime, quarter or any ridged object. There is no need to align the cover in any way, by rotating the cover the coin will automatically be drawn down into a slot molded into the lid. It is by this action that the coin interlocks the lid and cover, allowing the cap to be threaded off of the bottle. The inverted orientation of the cap and bottle prevents the packaging from being stored on the shelf with a coin in the slot. The other means for opening the cap is provided for the able bodied. A push tab is located on the cap, by firmly depressing the tab a boss on the underside of the tab will join with the slot on the lid, interlocking the cover and lid for removal.



DEVELOPMENT

Initial sketches explored various forms. These forms were judged against present designs as well as considerations of production, shipping and packaging. 3-D models were tested for ergonomics. Working prototypes made of high density foam were constructed to assess various functions and features. Final drawings were produced on Auto-Cad 12. Throughout the process valuable criticism was sought from fellow students, faculty and volunteers from field testing.

EVALUATION

Working prototypes were taken to an American Arthritis Foundation office for testing by an arthritis sufferer and other staff. After a short explanation of the design the volunteer was able to open the design in approximately 15 seconds. Closing proved to be just as easy. The volunteer stated that this was the first CRSC that they could use. All other staff gave favorable comments.

A high density foam prototype was demonstrated to an elementary public school psychologist. It was their opinion that the cognitive abilities of a four year old are such that a four year old would attempt to physically remove the cap rather than to employ a tool.

Four prototypes were taken to a child care center where a dozen five year old children participated in testing the design. The children were not able toto physically pull the cap apart. Some children were able to understand the picturegrams on the bottle labels showing the insertion of a coin into the slot in the cover. Given a coin the children quickly learned how to open the cap.

DISCUSSION

Given the positive experience gained through the Arthritis Foundation volunteer the design appears to be appropriate for use by the physically challenged. The overall size and shape seem to work for these individuals. What remains unclear is how successfully the cap can thwart the efforts of children. The child care center test highlighted how quick children learn things. Granted the children at the center were five years old where as the Consumer Product Safety test will use children four and younger. The children at the center had less trouble understanding the use of a coin than did most adults who were shown the cap. Although at the child care center an interesting accident occurred. The four high density foam prototype began to degrade from the children playing with them. The slot cut into the top of the lid of the prototypes began to open up due to the crumbling of the foam. This unintended alteration created a situation where the inserted coin would bob up and down in the slot rather than feed down into the lid. The children would rotate the cap and the coin would not interlock the cap and lid, although a very slight pressure on the coin would be all that was needed to cause the coin to interlock. The child did not discover this nor could they master the action after being shown the extra trick needed to open the bottle.

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ACKNOWLEDGEMENTS

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David Towle, M.P.S. Psychologist.

QUALITY OF LIFE IMPROVEMENT WITH VIBRATIONS

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ABSTRACT

Providing stimulation to students, part of the philosophy of inclusion, is a primary educational goal at Rosedale School. For students with multiple physical disabilities, vibration is one of the most effective forms of stimulation. Studies have also shown the therapeutic value of vibration. Under proper supervision vibratory stimulation produces increased interaction between the student and environment and basic quality of life improvements. To facilitate this supervised stimulation, the team designed and manufactured a device capable of delivering low amplitude vibration (≤ 2 mm) to the student while maintaining flexible and simple operation.

BACKGROUND

The faculty and personnel of Rosedale, a school for students with disabilities and a member of the Austin Independent School District (AISD), operate with several goals in mind, such as the physical and mental education of their students as well as the improvement of both work and social skills. Physical education quite often is used to improve the range of motion of a student, whereas mental education increases the cognitive ability. Work and social skills center around normalization, the inclusion of students at Rosedale into the community.

An important aspect of any teaching is the responsiveness of the students. A responsive student participates and learns much more readily than a withdrawn student. To this end, interaction between students and teachers at Rosedale makes use of many different skills, methods, and tools. The responsiveness of the student is increased by both putting a student at ease and providing them with a stimulus to which they can respond.

While many students respond to stimuli such as sound and light, there are some who only respond positively to vibration. At Rosedale, vibration is generally used with students who have profound cognitive and physical disabilities. One student in particular, "John," has been observed to be extremely tactile defensive and only respond to vibration, specifically a commercial, hand-held massager [1]. In many instances, the massager is used to calm an upset student. When the massager is set in his hand, "John" places it near his ear and holds it there. This has a two-fold benefit in that the vibrations calm "John" and holding the massager is physical therapy for his hands. Not all students can necessarily benefit from holding a massager. In some instances, a student may need vibrations for stimulus, allowing focus on another learning or therapeutic activity. However, actively holding the massager in their hand can detract from other activities.

STATEMENT OF THE PROBLEM

The goal of this project was to design and fabricate a device capable of supplying a vibrational stimulus to a student. The vibrations may be used to increase the responsiveness of the student so that teaching and therapy can ensue. Vibrations may also be used to teach cause and effect relationships. Additionally, should a student become upset, the vibrations can be used to soothe the student.

DESIGN

In the solution of any problem, especially design problems, an organized approach is extremely beneficial. A structured approach to design assists engineers in creating safe, useful products by reducing oversight, creating extensive documentation of the process, and ensuring the voice of the customer is heard throughout the design. The authors applied the methodology set forth by Ulrich and Eppinger to the design of a vibrational device [3].

The first step in the methodology is to determine what the customer wants through site visits, observation of the currently used system, and customer interviews. Using Quality Function Deployment (QFD), the design team then translates the customer needs into quantified engineering specifications [3].

The specifications are then used throughout the rest of the design process; concept design, embodiment design, and prototyping. Prototypes are the first opportunity for the design team to present the design to the customer for evaluation. Customer feedback provides insight into problems or overlooked design issues. These problem areas and oversights can be redesigned and implemented before the product goes to final production.

To facilitate embodiment design, the design team broke the overall system into components: a vibration unit, a padded holder for the vibration unit, a control box, and a power system. The vibration unit creates the actual motion resulting in the vibrational stimulus. The holder allows stimulus transmission to the student. The control box provides a means of controlling vibration intensity. The power system supplies the needed energy to the vibration unit. Having demonstrated feasibility, the team was able to proceed to construction of an alpha prototype.

It is worthwhile to discuss the safety and response of the students in terms of this design project. The two primary questions to consider are, "How do the vibration frequency and amplitude affect the student's response?" and "Is there any potential damage to the vestibular system or a negative impact on the student's proprioception?" Because students at Rosedale are often non-communicative, the student response to vibration and it's impact on proprioception is determined by observation of physical cues. This observation must be performed by people who are both qualified to do so and familiar with the student in question. This is routinely done at Rosedale, so that any detrimental effects of the vibrational device can be readily detected. At the vibration level of this device, tests have shown that physical damage to the vestibular or other physiological systems can be ruled out [2].

DEVELOPMENT

With a thorough understanding of the customer requirements and resulting design issues, the design team created an alpha prototype demonstrating the design both in terms of functionality and manufacturability. The team designed and constructed each of the individual system components discussed above. The primary component of the vibration unit is a small direct current (DC) motor with an off-centered mass mounted to the shaft. The motor/mass assembly provides a very quiet and low cost means to generate vibration. In a room with normal conversation, the motor cannot be heard. A short length of polyvinyl chloride (PVC) pipe is used as a housing for the motor/mass assembly. The padded holder, resembling a blood pressure cuff, is sewn out of dark blue denim with nylon padding inside. The vibration unit is removable which allows machine washing of the holder. The control box houses an on/off switch, connectors for power transmission, and potentiometers, or variable resistors, for speed control. Through the use of multiple connectors, five as specified by the customer, several vibration units can be connected and independently controlled. Lastly, the power system consists of two primary components. The first is an alternating to direct current (AC-DC) adapter. This allows the device to be powered using wall current. The second component of the power system is male and female RCA plugs, combined with speaker cord. These plugs and cords are commonly seen on home stereo equipment. The use of the plugs allows holder disconnection from the control box in case any of the holders are not used.

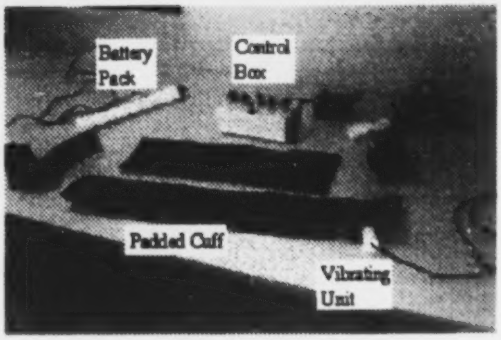

Figure 1: Beta Prototype.

The team presented the alpha prototype to our customers at Rosedale, where it was tested on two students, "John", discussed above, and "Bill". "Bill" also has profound cognitive disabilities and is extremely physically involved. "John's" response to having a vibration device attached to his arm, as interpreted by the classroom staff, was positive and beyond that expected. Generally withdrawn due to his tactile defensiveness, "John" moved his arm with the vibration device attached and put the device near his ear. According to the classroom staff, this movement is rare for "John" and has potential physical therapy implications. "Bill", having the vibration device placed on his forearm, was initially pleased but quickly became upset. This reaction very quickly revealed an oversight in the design. "Bill" was not able to remove the device from his arm. Given the opportunity to hold the device, "Bill" both held it near his ear and began to mouth the device. After several moments, he dropped the device. "Bill" also attempted to grab the power cord to the cuff. The classroom staff expressed concern over the dependency on wall current as a power source. During trips off-campus, such as to a restaurant or worksite, a wall plug may not be readily available. Lastly, one of the staffmembers observed that, with longer cords to the vibration devices, they could be used with multiple students.

The design team used the information gained from the alpha prototype to create the beta prototype, shown in Figure 1. The beta prototype included device redesign as well as functionality addition. First, the holder was redesigned to also allow hand holding, if desired. Now a variety of holders are offered to the customer to allow attachment around an arm or leg, or holding in a student's hand. The speaker cord was changed to black lamp cord, reducing the cord's visibility, and the length was increased to eight feet. For increased portability and convenience during off-campus trips, a battery pack, with integral speed control, was also designed and constructed. Lastly, the vibration units were sealed against liquids, increasing student safety should they mouth a holder.

DESIGN EVALUATION

Commercially available, low cost hand massagers are currently used to provide a vibrational stimulus to many of the students at Rosedale. However, use of these readily available devices comes at a cost beyond that of the price tag. During off-campus visits escorting the students from Rosedale, teachers and assistants are aware of the stares from people unaccustomed to people with disabilities. These uncomfortable stares are increased when a student uses a hand-held massager for comfort. In addition, should a student need their hands for some other work or learning activity, holding a hand massager can limit their actions. It is important to note that some students benefit from the action of holding or grasping a hand massager.

The vibrating pads, created by the design team, address all of these issues. The holders, resembling blood pressure cuffs, are extremely normalizing. Many people are familiar with blood pressure cuffs and will not give the padded holder a second look. The holders, affixed to a student's arm or leg, will not interfere with any hand-oriented tasks a student may undertakes. However, if a student's task is to actually hold the vibration device, this functionality has been maintained. The vibrations comfort the student and aid them in interactions with their environment. As with many engineering designs, the current project had common specifications such as durability, low cost, and safe use. The vibration device, however, goes beyond these issues and tackles quality of life head on.

CONCLUSIONS

The overall design statement for this project, as discussed above, is the creation of a device capable of supplying a vibrational stimulus. The vibration device satisfies the design team's mission by providing localized vibratory stimulation, allowing user control of frequency and operation at a safe vibration level.

Customer needs, such as low cost, ease of use, safe operation and durability, are all met. The social and psychological needs of the students are also evaluated. This evaluation impacts the design by emphasizing that the product not stand out in public.

The students at Rosedale who tested this device reacted positively, with only one notable exception. The one negative reaction, however, led to product improvements which are incorporated into the final prototype.

Future development of this device must address several possible areas for improvement. In particular, part count and assembly time need to be reduced. The device fabrication and assembly do not require any specialized skills, but they do involve many steps.

The bottom line is that the design of the vibration device meets all engineering requirements. More importantly, through continuous customer interaction, the vibration device evolved into a product that meets the needs of the students, faculty, and staff of Rosedale School.

ACKNOWLEDGMENTS

We wish to express our thanks and gratitude to a number of people. First, to the students, faculty and staff of Rosedale School for providing such a worthwhile and exciting project, as well as for all of their assistance throughout the project. Thanks also go to the faculty instructors for the engineering and social work classes. Their tireless work motivated us in our endeavors, not only making us better professionals, but better people. Our acknowledgments would not be complete without extending our deepest gratitude to Mary Leah Neill. Her outstanding seamstress skills helped make our design what it is today.

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BUS STOP LOCATOR: AN APPLICATION OF AUDIBLE SIGNAGE TECHNOLOGY

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Abstract

The Bus Stop Locator, a device used to assist people with visual impairments in locating, traveling to, and finding out information about bus stops, is described. Problems encountered by people with visual impairments in accessing and using public transportation are given. The limitations of proposed and developed audible signage technology are discussed. Results of preliminary trials and planned modifications for this design are given.

Background

According to the Bureau of the Census, 9.7 million people in the United States are unable to read printed signs at normal viewing distance.[1] Additionally, estimates of tested acuity classify 1.1 million people as legally blind (corrected acuity of 20/200 or less or visual field of <20°).[2]

Visual impairments vary significantly in effects and degrees. Effects of disability may be lessened with education and training. Moreover, individual differences in preferences and education may present challenges for persons and organizations making accommodations for people with visual impairments.

Uses of audible signage to assist people with visual impairments have been proposed and developed. Most employ amplitude modulation (AM) or frequency modulation (FM) radio, inductive loop, or infrared technology. One infrared system (Talking Signs, Inc.) is currently used in San Francisco, California, transit facilities. This system relies on light-emitting diodes to transmit digitally encoded human speech messages. A hand-held receiver picks up, decodes, and plays the message.

Statement of the Problem

The Miami Valley Regional Transit Authority (RTA) in Dayton, Ohio, has developed and implemented comprehensive route training programs to assist people with visual and other disabilities in accessing and using public transportation. However, one of the more vexing problems for bus riders with visual impairments has been locating bus stops in unfamiliar areas.

The Bus Stop Locator is a response to a need communicated by RTA regarding bus stop accessibility for consumers with visual impairments. Currently in the Dayton area, no assistive mechanism exists to enable blind or visually impaired persons traveling in unfamiliar areas to easily locate and access bus stops and route information.

Rationale

For the sighted bus patron, cues as to bus stop location and bus identification are easily distinguished by signs, bus shelters, and other visually distinctive features. To the visually impaired patron, signs and other visual information may provide no assistance, and these people may become lost or involved in possibly dangerous situations because they cannot find bus stops in an easy and timely manner. The risk is increased when people travel in unfamiliar areas or on complicated routes (such as those requiring multiple transfers). Recent accidents involving experienced blind subway and bus riders on their everyday routes have emphasized the need for a more comprehensive accommodation program.[3]

Often, blind and visually impaired bus riders must depend on others for information regarding bus stop location and bus identification. This situation not only is inconvenient for both parties but also poses significant danger to the visually impaired people who must place themselves at the mercy of strangers. The information given may be less than accurate and complete. Additionally, at night and in less frequented areas, no one may be around to offer assistance. Finally, people with visual impairments simply do not like to be dependent on others for information, especially if suitable alternatives are available.[4] Clearly the need exists to assist people with visual impairments in locating and accessing bus stops and basic bus information (street, direction of travel, etc.).

Available and past approaches to audible signage transmit continuously (and thus require continuous power supply), require the user to be in the line-of-sight for activation, are cost prohibitive, require users to wear conspicuous devices, and/or do not make route information available to people without receivers.

Design

The design involved two major needs: a method for the user to interrogate the area for information on the location of a bus stop and a method for the bus stop to inform the user as to its location and provide suitable information about the bus route.

The method chosen to interrogate the area consisted of a hand-held, two-channel radio transmitter. At the bus stop, a two-channel radio receiver was used to decode the transmitted signal. The output from the receiver activated either an audio location beacon or a recorded message.

Also included was a push button at the bus stop which activated the recorded message. To meet environmental needs, the specifications called for operation over -30° to 120°F and the ability to withstand driving rain, freezing rain, and snow. The device also needed an operational range of at least 50 feet. It was preferred that the bus stop unit be independent of the power line mains for internal power.

Development

During development, input was sought from blind persons through the Clovernook Center in Cincinnati, Ohio, and the Wright State University campus. The basic idea was well received. It was made clear by the consumers that the transmitter should be unobtrusive and not call attention to the user.

A commercially available radio transmitter and receiver (Linear) were used. This assured that the system would meet FCC requirements and use proven technology. The transmitter is similar in size to a garage door opener and can be activated from within clothing. The audio location beacon consists of a single-frequency tone (Floyd Bell). For the bus stop information, a digitally recorded message is recorded (ISD) and played back through a weatherproof speaker. Power is provided by a 12-volt sealed lead acid battery. A solar panel is used to keep the battery charged.

A demonstration prototype was built in a hermetically sealed housing, which could be mounted to a pole. To meet temperature requirements for the region, the system was designed to operate from -40° to 140°F.

The transmitter had two buttons providing two different signals to the receiver. One button was labeled with the Braille symbol for "S" (signal), the other was labeled with a Braille "V" (voice). The "S" button triggered the location beacon and the "V" button the recorded message. The beacon would sound as long as the "S" button was depressed. Once triggered, the message continued to the end. The message could be as long as 16 seconds.

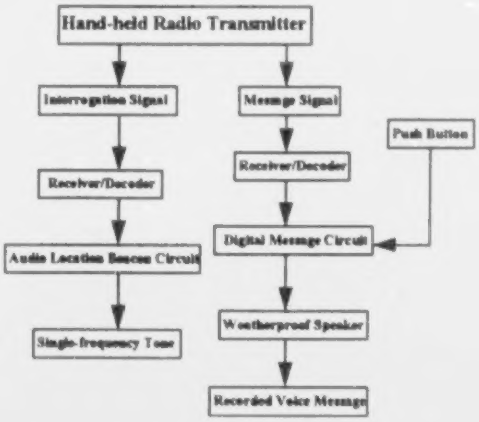

Figure 1. Block Diagram for Bus Stop Locator.

Evaluation

The prototype has been presented to the RTA Committee on Regional Transportation Accessibility. The reaction from a blind committee member was very enthusiastic. "When can I have one?" he said. The members representing Mental Retardation/Developmental Disabilities wanted the device for their consumers. The prototype design was tested by RTA and two consumers who are blind at a downtown location for three days in November 1995. The battery operated the unit during this time with no difficulties in temperatures below

20°F. Again, feedback was positive. RTA requested a second testing date in order to allow more users time to analyze the unit. The consumers stated that the device was very useful and provided helpful, directional information to help them locate, travel to, and get information from bus stops. Suggestions for improvement made by RTA included making the signal louder in heavy traffic conditions and tapping into power from the street lights.

Discussion

The demonstration prototype successfully meets the basic requirements. It provides an unobtrusive way for a blind user to activate it. It produces a signal that enables the user to locate the bus stop and a recorded message that informs about route information. The device can be activated without the user being in the line-of-sight of the radio transmission. A push button mounted with the unit provides information to others at the bus stop.

A second prototype is in development that will improve upon the first one. The main consideration is to provide an audio beacon and recorded message that automatically adjust their volume to the environmental background noise level. A disadvantage of most of the available systems is that they do not adjust for ambient volume conditions. When traffic or other background noise increases, volume does not automatically adjust in response. This feature is especially important in the case of bus stop signaling devices, which are frequently around high-traffic areas. By decreasing in volume in response to decreased environmental noise, the device would be less bothersome and distracting to individuals who live or work near the sign or persons waiting at the bus stop.

Other desired changes are:

- reducing the size of the unit, thereby making it less noticeable to the general public and less of a target for vandalism;
- building one tone-emitting/messaging circuit;
- finding more compact solar recharging cells; building in AC/DC power supply options; and
- developing circuits that require little to no power in standby mode.

A second set of tests will be performed in December 1995 with more consumer trials to get data on battery duration, solar recharging, and temperature response.

While the focus of this project is on visual impairment, a number of other disabilities negatively impact a person's ability to read and interpret printed material: stroke, head injuries, autism, mental retardation, dyslexia, and illiteracy. Thus, the disability assisted by the Bus Stop Locator may be described as any number of conditions that inhibit or prevent a person from reading and interpreting visual information.

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OCCUPATIONAL REHABILITATION CENTER

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ABSTRACT

A local hospital desired a "next-step" facility for the rehabilitation of industrial workers trying to return to the work force. It was essential that this facility was an accessible, controlled area which could be used to train individuals with temporary or permanent disabilities to return to an industrial vocation without risk of further injury. The final product, the occupational rehabilitation center (O.R.C.), was designed as a set of work stations where patients graduating from the traditional rehabilitation program could seek advanced occupational therapy and vocational training in an atmosphere typical of their given occupation. Since its opening in July 1995, the workstation has been used by patients recovering from illness or injury to return to their former jobs, to acquire another job, or as a means of evaluation of cognitive abilities by hospital therapists.

BACKGROUND

The occupational rehabilitation center (O.R.C.) was designed with the intent of providing the hospital's "Work Link" program with an industrial rehabilitation center which would subject patients to a realistic environment where rehabilitation could be tailor-made to individual needs. Although the hospital's previous "Work Link Program" provided patients with a means of physical rehabilitation through exercise, therapists were not able to prepare patients for their return to a specific occupational activity or to evaluate the appropriateness of the re-entrance to the former job environment. The O.R.C. is utilized as a next-step rehabilitation center where patients and therapists work together on specific body mechanics and cognitive skills in order to strengthen a particular feature of the patient or to practice techniques which could prevent future injuries to the patient and return or initialize the job entrance. The student group spent over 400 hours in design, development and construction of the center. The benefits were not only the design experience, but also the professionalism and project management that was needed to successfully complete the project.

The student group completed the project under a three thousand dollar budget, this was in contrast to the one hundred twenty thousand dollar estimate for the project to be completed by an independent contractor which was consulted by the hospital.

DESIGN ANALYSIS

The O.R.C. was designed through the combined efforts of the student design team and rehabilitation staff members. The therapists requested general areas which would augment their current industrial rehabilitation program. The student team designed specific components which would fulfill the requests of the hospital and be compatible with the available floor space. The Center was required to fit into a fenced-in sixty-five foot by twenty foot section of a parking garage located below the hospital.

After consideration of the necessary stations which would be needed for the center, a rough floor plan was designed. The floor plan consisted of three main stations: an automotive station, a plumbing, electrical, and general construction station, and a general labor station. Each station included several sub-stations which would allow the patient and therapist to concentrate on performing a particular exercise in order to rehabilitate a specific injury. The student team worked as a cross disciplinary team with the therapists to decide on the specific activities that would incorporated. The designs of the sub stations were developed through analysis dealing with structural integrity, strength of materials and manufacturibility. Ongoing adjustments were applied to the substations in order to accommodate various physical and feasibility limitations of the project. To ensure that all facets of the Center were realistic and in compliance with local codes, research was performed through consultation of various private contractors, therapists, university professors, and local libraries. The final design was reviewed and approved by the facility engineering staff of the hospital.

DEVELOPMENT AND EVALUATION

The configuration of the three stations served as a means to isolate patients into an area specific to their occupation. Though the floor space was minimal, each station was designed to allow patients to work in an accessible environment similar to their actual vocation. All stations also provided the basic requirements for proper simulation of the patient's occupation while allowing space for modification and improvements.

The automotive station was created for a large range of patients. Planned around the donation of two automobiles, this station will be able to aid patients ranging from automotive technicians to chauffeurs. A Saturn sedan with an automatic transmission and a MG convertible with a manual transmission were placed side by side near the entrance of the Center. The Saturn was mounted on a structure that would allow the front to be elevated by a car jack, but would not allow any other movement to ensure safety. The MG convertible was permanently mounted onto stands that would allow a patient to work underneath the vehicle on his or her back without danger of the vehicle swaying.

Another sub-station of the automotive work station was a six foot by three foot metal frame containing the elements of the undercarriage of an auto. This station was elevated eight feet off of the ground in order to simulate a vehicle being worked on from below. The elevated frame was designed to allow patients to work on the underside of a auto, who otherwise would not be able to physically lower themselves below one of the actual vehicles.

The largest station in the O.R.C. was the plumbing, electrical, and general construction station. This station focused on a twelve foot by eight foot wood-framed room which contained the electrical, construction, and a portion of the plumbing sub-stations. The room contained fifty feet of *Romex* electrical wiring, three outlet boxes, one lighting fixture, one light switch, a vanity sink with faucet, and seventy five feet of PVC piping. Sharing a wall with the room was a platform elevated three feet from the ground with a shower stall containing a faucet and drain which utilized hot, cold, and drainage plumbing. A five step staircase was placed at the end of the platform to provide the patients with a means of reaching the shower stall and to provide a site for the patient to practice hauling objects up a set of stairs.

In order to create the most realistic environment possible, the wiring and plumbing in this station was placed overhead, inside walls, and inside a three foot by three foot, eight foot long confined crawl space under the shower platform. The wiring, plumbing, stairs, and door frame were all constructed according to local codes.

The final work station was designed to rehabilitate general laborers such as steel and factory workers. One of the sub-stations of this area, an I-beam elevated one foot off of the ground by two four inch square wood beams at either end, was implemented as a mechanism to test the patient's agility and coordination. In an exercise which would simulate the everyday process of a common steelworker, the patient would be asked to traverse, strike, or align the six holes in the I-beam with the six holes on a custom gusset plate located on the end of one of the supporting beams. The second sub-station in this area was a eight foot by eight foot wooden frame which supported an I-beam containing a trolley and hoist capable of supporting two thousand pounds. The frame for the trolley and hoist was designed with a safety factor of 4, to ensure safe operation of the largest mechanism in the O.R.C.

DISCUSSION

The O.R.C. was built as an authentic link between the traditional clinical rehabilitation atmosphere and the industrial working world. The O.R.C. incorporates a realistic environment in addition to functional rehabilitation devices, such as the automobiles and the twelve by eight room. The first step of the "Work Link" rehabilitation program allows the patient to practice isolated movements through weight training and simple exercises, while the O.R.C. allows the patient to work on specific functions or processes directly linked to his or her particular occupation. To accommodate the needs of all patients, the O.R.C. was designed to meet A.D.A. accessibility standards.

BEST COPY AVAILABLE

O.R.C.

The "real-world" setup of the O.R.C. was not only necessary to accommodate the patients physical needs because the mental aspect of industrial rehabilitation is extremely arduous and difficult to control. Therefore, the environment in which the patient is rehabilitated must be appealing to the patient while useful to the therapist. The process must prepare the patient for the shock of re-entering the work force while allowing the therapist to complete a thorough evaluation of the patient's progress.

Currently, therapists who have been using the center since July, 1995 have reported that the ability to simulate a real-world working environment, observing patients performing various activities and educating them on the appropriate body mechanics has allowed for a more thorough and comprehensive rehabilitation program than was possible in their traditional rehabilitation program. The therapists are currently collecting long-term data from their patients in order to determine the over all impact of this type of "hands on," therapy compared to traditional weight, flexibility and range of motion therapy.

ACKNOWLEDGMENTS

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Whitaker Student Scientific Paper Competition

1996 RESNA/Whitaker Student Scientific Paper Competition

On the following pages you will find the five award winning papers for the third annual RESNA/Whitaker Student Scientific Paper Competition. These awards are supported through the generosity of the Whitaker Foundation. The purpose of the Student Scientific Paper Competition and Awards is to encourage and promote student participation in high quality research related to the fields of rehabilitation engineering and assistive technology. The competition is intended to encourage students from a variety of disciplines to address issues in the field of assistive technology and submit papers for presentation at the annual RESNA conference. This competition is based on scientific merit of the reported research and is structured to be distinct from and complimentary to the student design competition.

The winning papers in the Whitaker Competition were all presented in a special session at the RESNA '96 Conference. This session is unique in that it provided a forum which, in addition to highlighting student research activity, brings together papers on diverse topics for presentation. There were a total of 22 papers submitted for the competition this year. Members of the Student Scientific Paper Competition Committee scored each paper after careful review based on the following criteria.

- General quality of the writing and presentation.
- Clear statement of hypothesis or research issues to be addressed.
- Choice and description of appropriate methodology.
- Presentation of the results.
- Discussion of the results and their significance.

I would like to sincerely thank the review committee for this year's competition: Donald McNeal, Ph.D., Hunter Peckham, Ph.D., Michael Rosen Ph.D., and Machiel Van der Loos, Ph.D. They faced very difficult decisions in choosing the five winners as most of the papers were deemed meritorious. Very careful consideration was given to avoid any potential conflicts of interest by 1) blinding the reviewers to the authors and their institutional affiliations (to the best of our abilities), and 2) choosing reviewers who had no association with any of the authors or papers.

On behalf of RESNA I wish to thank the Whitaker Foundation for its support, the judging committee for a difficult job well done, and all the students who submitted papers. I invite students to start planning their research for submission to the 1997 RESNA/Whitaker Student Scientific Paper Competition.

Simon P. Levine
Chair, RESNA/Whitaker Student Scientific Paper Competition

DETECTION OF EVENT-RELATED POTENTIALS AS THE BASIS FOR A DIRECT BRAIN INTERFACE

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ABSTRACT

Electrocorticograms (ECoG) were collected from five subjects performing simple voluntary activities. Templates of event-related potentials (ERPs) corresponding to the activities were created from half of the ECoG using triggered averaging. The templates were then cross-correlated with the other half of the ECoG. Detections were identified each time the cross-correlation statistic exceeded an experimentally determined threshold. Detections which occurred within one second of an actual movement were considered valid detections. Three of the subjects had at least one activity that could be detected with greater than 85% accuracy and for which less then 5% of the detections were considered to be false-positive. These results show that detection of voluntary cognitive activity using cross-correlation of ERP templates with ECoG data could form the basis of a direct brain interface.

BACKGROUND

The term direct brain interface refers to an interface that detects specific voluntary cognitive activities and triggers appropriate external responses. Such an interface could provide people with severe disabilities with an option for control of assistive technology that does not require physical movement. Over the longer term, a direct brain interface might also be useful for people with less severe limitations.

The work described here focuses on movement-related cognitive activities because the occurrence of movements can be precisely determined. This allows accurate evaluation of methods developed to detect voluntary cognitive signal patterns. Although a potential user of a direct brain interface may be unable to perform physical movements of the type studied here, the methods developed to detect cognitive signal patterns related to movement are expected to be applicable to the detection of signal patterns related to attempted movement or other cognitive activities.

Cross-correlation of a signal template with electroencephalogram (EEG) [2],[5] or electrocorticogram (ECoG) [5] has been used to detect human sensory evoked potentials. Cross-correlation methods have also been used to detect signal patterns related to movement in animals with up to 83% accuracy [6]. The use of cross-correlation for the detection of signal patterns related to movement has not yet been demonstrated with human subjects.

RESEARCH QUESTION

The research hypothesis is that a method based on cross-correlation of a signal pattern template with ECoG can detect ERPs associated with voluntary movement in humans with sufficient accuracy for the operation of a direct brain interface. The accuracy of detection is measured in terms of percentages of valid and false positive detections.

METHODS

Data collection: The subjects for this research are patients in an epilepsy surgery program who have cortical surface electrodes implanted for diagnostic purposes prior to ablation surgery. Data was collected from five subjects, each of whom performed approximately fifty repetitions of up to four distinct activities, resulting in ECoG data sets from 18 subject-activity pairs. Each data set contains ECoG from 20 - 31 cortical locations.

The electrodes are 4 mm in diameter and separated by 1 cm center-to-center. Electrodes are arranged either in one dimensional strips of 4 to 6 electrodes or in two dimensional grids of up to 64 electrodes. The preferred electrode configuration for this research is electrode grids positioned over sensory-motor cortex. Electrode configuration is chosen solely for diagnostic purposes, however, and is most commonly over the temporal lobe, with a few electrodes over tongue sensory-motor areas. A summary of electrode placement and configuration for the five research subjects is presented in Table 1.

Subject	Electrode Type	Electrode Location
DT	Grid	Temporal Lobe
JR	Strips	Temporal Lobe
DV	Grid	Sensory Motor Cortex
JP	Grid	Temporal Lobe
DP	Strips	Temporal Lobe

Table 1: Electrode type and location by subject.

Triggered averaging of the first half of each data set is used to create a signal pattern template for every electrode location. The triggered averaging is based on a switch closure activated by the given movement. Details of the triggered averaging have been previously described [3]. Templates begin 2.5 seconds before the trigger and end 1.5 seconds after.

ERP identification: The templates produced by the triggered averaging are identified as valid ERPs through the comparison of a pre-activity interval and a peak signal interval (see Figure 1). The pre-activity interval is defined to be from 2.5 to 2.0 seconds prior to the trigger, well before the earliest reported time for signals related to the initiation of movement [4]. The data from the pre-activity interval is used to calculate the pre-activity mean and the 95% predictive interval for future observations, based on the Student T-test. The template is then shifted by this mean (to prevent biasing) and rectified. The position of the maximum value in the rectified template is determined and a peak signal interval a half second in duration is selected centered around the maximum value. The signal mean over this peak interval is calculated.

The ratio of the peak signal mean to the 95% predictive interval amplitude is used to select ERP templates for cross-correlation analysis. Templates with ratios greater than two were used.

Cross-correlation: The signal pattern template and the ECoG from the second half of the data set are cross-correlated. A detection is identified when the cross-correlation statistic exceeds an experimentally determined detection threshold. An identified detection is accepted as valid if it is within one second before or after the time at which the movement actually occurred (as recorded by a mechanical switch). The detection threshold can be adjusted to provide a balance between the percentage of movements detected (hit percentage) and the number of incorrect detections (false-positive percentage). These performance statistics vary based on the level of the detection threshold (see Figure 2). Three different detection thresholds are selected for each data set in order to more fully explore the detection achievable with cross-correlation. The three thresholds are determined by a function which minimizes the false-positive percentage (F) and maximizes the hit percentage (H) based on weightings of H versus F. H/F weighting ratios of 1/1, 10/1, and 1/10 were used.

RESULTS

Valid ERP templates were identified for 15 of the 18 subject-activity data sets (Table 2). For each subject, at least two activities produced valid ERPs. Several of the subjects had at least one ERP corresponding to each of the activities performed. As would be expected due to the typical electrode placement, four of the five subjects had ERPs related to tongue protrusion.

Subject DV had the best electrode configuration for research purposes, a grid placed over sensory motor cortex. At least one valid ERP template was identified for each activity performed by this subject with the largest number identified for tongue protrusion. All tongue related ERPs were recorded from nearly contiguous locations on the electrode grid (see Figure 3). Stimulation studies performed on this subject by the epilepsy surgery program showed that the grid was placed primarily over tongue sensory-motor areas.

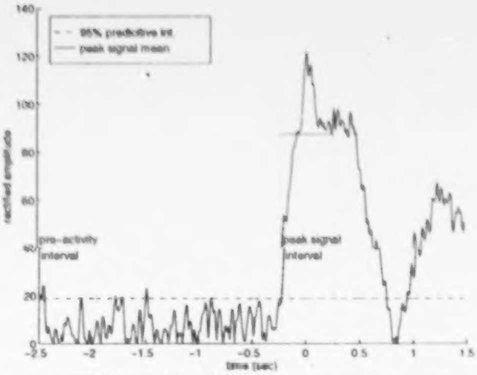

Figure 1: ERP identification for averaged template.

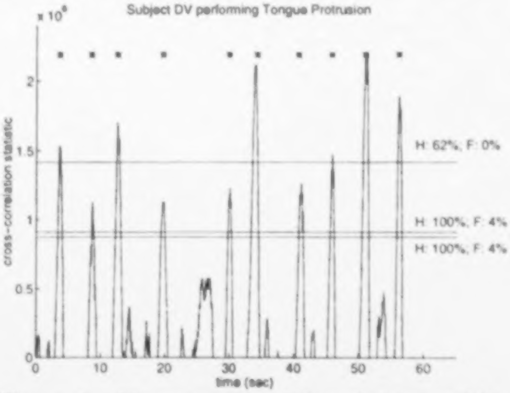

Figure 2:. Hit percentage (H) and false-positive percentage (F) at the three detection thresholds. Asterisk (*) indicates time of first 10 movements.

Activity	Subject				
	DT	JR	DV	JP	DP
Tongue Protrusion	0/24	10/20	7/31	3/31	11/20
Facial Movement	1/24				
Verbalization	1/24			3/31	
Sip	0/24	3/20			
Naming				1/31	
Thumb to Palm			1/31		4/20
Wrist Extension			6/31		5/20
Arm Rotation			2/31		
Puff				3/31	
Finger Extension					2/20

Table 2: Valid ERPs identified from the first half of each subject/activity data set. Entries are the number of valid ERPs templates over the total number of templates.

For the detection thresholds selected based on to an H/F weighting ratio of 1/1, three of the five subjects had at least one activity that could be detected with greater than 85% hit percentage and less than 5% false-positives percentage (see Table 3). The remaining two subjects also had high hit percentages, but these were coupled with false-positive percentages of 40% or greater.

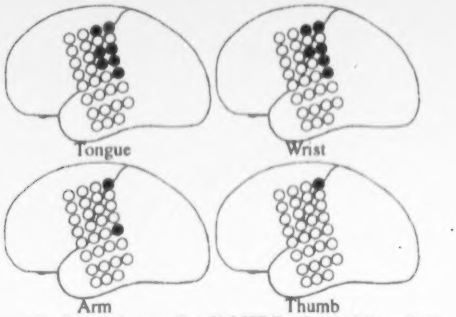

Figure 3: Locations of valid ERPs for subject DV.

Activity	Subject				
	DT	JR	DV	JP	DP
Tongue Protrusion		92/2	100/4	89/16	72/40
Facial Movement	100/62				
Verbalization	100/70			72/15	
Sip		100/48			
Naming				82/21	
Thumb to Palm			12/18		96/64
Wrist Extension			77/22		88/64
Arm Rotation			36/5		
Puff				89/2	
Finger Extension					84/54

Table 3: Detection accuracy with detection thresholds selected with an H/F weighting ratio of 1/1. Entries are in the form H/F. When multiple ERPs were identified for the subject-activity data set, the electrode location with the maximum (H-F) difference is presented.

The best detection accuracies for the 1/1 H/F weighting were 92/2 (JR), 100/4 (DV), and 89/2 (JP) (see Table 3). When the detection threshold was based on a H/F weighting ratio of 1/10, these accuracies changed to 77/0 (JR), 62/0 (DV), and 43/0 (JP). When the hit percentage was emphasized with a H/F weighting ratio of 10/1, the accuracies changed to 100/41 (JR), 100/4 (DV), and 96/38 (JP).

DISCUSSION

The detection accuracy obtained for three of the five subjects shows that it may be possible to detect ECoG signal patterns related to voluntary cognitive activities with sufficient accuracy to operate a direct brain interface. These results are especially impressive because the location of the electrodes could not be specified. Improved accuracy should be possible when the electrode locations can be chosen for the purpose of detecting ECoG signals related to a specific activity.

A portion of the false-positive percentage may be a result of the measurement techniques. The identification of detections as either valid hits or false-positives is based on their proximity to the recorded triggers. However, the trigger channel only records activities which result in the activation of the mechanical switch. Thus, activities which are actually performed (or just planned) but do not activate the switch could add to the false-positive percentage. The dramatic drop in the hit percentages for the three best detection accuracies when a H/F weighting ratio of 1/10 was used is consistent with the hypothesis that some of the false-positives were actual movements which did not result in switch activation. Future experiments will address this uncertainty by the use of an improved trigger such as electromyography.

Detection of voluntary cognitive activity by means of cross-correlation relies on the availability of an ERP template specific to a particular subject, electrode location and activity. There are several possible methods by which such templates may be obtained for people with severe disabilities. First, templates could be established during the course of a progressive degenerative illness. Second, advanced signal processing methods may be able to identify templates based on the content of the ECoG signal alone [1]. Third, templates representative of typical ERPs could be used. Cross-correlation between signal templates and ECoG could therefore form the basis of a direct brain interface for people with severe disabilities.

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Control of Neuralprostheses III: Self Adaptive Neuro-Fuzzy Control Using Reinforcement Learning

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ABSTRACT

Preliminary results are presented of a new functional electrical stimulation (FES) control methodology based on an adaptive fuzzy network (AFN) trained using supervised and reinforcement machine learning techniques. The FES application example used to test these controllers used a computer model of swing phase assisted by a powered hybrid FES orthosis. An open-loop controller was optimized and used to compare the performance of the new AFN controllers. The supervised learning controller was able to converge to a control strategy similar to that of the optimized open-loop controller in typically ten trials. Using very simple reinforcement signals, the reinforcement learning AFN controller was able to converge to the optimized open-loop strategy after several hundred trials. The reinforcement learning controller has the additional ability to continually re-adapt to changes in the system parameters which caused the other controllers to fail.

BACKGROUND

The powered hybrid system for paraplegic gait shown in figure 1 is based on the modular hybrid orthosis proposed in [1]. It consists of floor reaction orthoses (FRO) [2] worn on each leg plus a hip brace which restricts leg movement to the sagittal plane. An actuator positioned at each hip joint produces variable external torque. In addition, a pair of surface electrodes is positioned on each thigh to provide functional electrical stimulation (FES) of the knee extensor muscles. A controller is required for this system which will control the hip brace actuator's torque output, and the FES pulsewidth.

This hybrid system was modeled as the simple compound pendulum shown in figure 2. A 3-factor knee extensor muscle model [3] was used to simulate FES. A 2,3-order adaptive step size Runge-Kutta integration algorithm was used to solve the model dynamics.

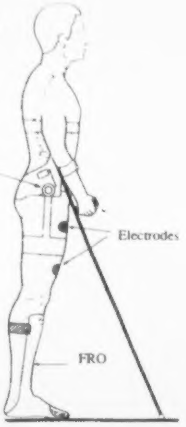

Figure 1. *Hybrid orthoses with floor reaction orthosis, powered hip brace, and FES electrodes positioned for quadriceps stimulation.*

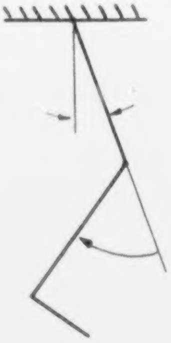

Figure 2. *Two-segment compound pendulum model of swing leg.*

RESEARCH QUESTION

What are the advantages of reinforcement learning over supervised learning in adaptive fuzzy networks (AFN)? How can reinforcement learning be used to continually re-adapt and cope with significant changes in the system parameters?

METHODS

First, a simple open-loop controller which provided two outputs, hip torque and knee extensor stimulation, was designed and optimized. The muscle stimulation was a rectangular waveform with adjustable mark-space timing. The hip torque was an exponential function with adjustable amplitude and on/off timing. The open-loop controller was optimized using a least-squares object function to achieve sufficient foot clearance with minimal energy output.

Two independent supervised learning AFN controllers were developed, one for hip torque control, and another for quadriceps stimulation control. Both controllers used two inputs, the hip and knee angle (assuming that these values were available), and provided two outputs, hip torque and quadriceps stimulation pulse width. Both of these AFN controllers used five Gaussian membership functions for each input and defined 25 fuzzy rules using the Sugeno-style inference method with fuzzy singletons [4, 5]. Both of these were trained using a gradient learning algorithm with the optimized open-loop controller as the training set.

Two separate reinforcement learning AFN controllers were also developed, one for hip torque control, and the other for quadriceps stimulation. Like the supervised learning AFN controllers, the reinforcement learning controllers used hip and knee angle for input. However, nine Gaussian membership functions were used for each input resulting in a greater rule base of 81 rules. This larger rule base is to ensure that there is accurate reinforcement predication.

Both reinforcement learning AFN controllers were trained using Williams' REINFORCE algorithm [6, 7] in conjunction with Sutton's Temporal Differences algorithm [8, 9]. The controllers were initialized with no knowledge of the plant. The reinforcement signal was on when the foot collided with the ground during mid-swing.

The effect of changing model parameters was examined for each AFN controller. Muscle output forces were reduced and increased to simulate fatigue and potentiation. Body mass and geometric parameters were altered simulating a change of patient.

RESULTS

After 15 trials, the supervised learning AFN controllers converged to a control strategy very similar to that of the optimized open-loop controller. Figure 3 shows the result of the learning.

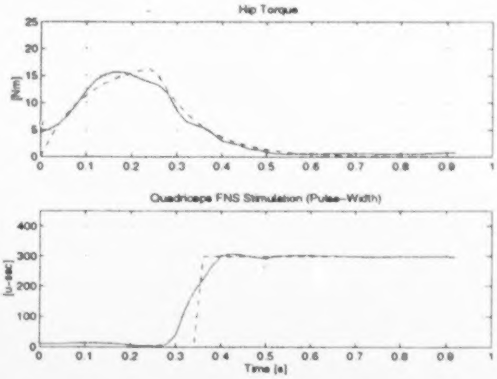

Figure 3. *Supervised learning AFN controller outputs. The optimized open-loop controller output is shown with dashed lines.*

When the quadriceps muscle output was decreased by 15%, the open-loop controller failed, while the supervised learning AFN was able to cope with the change and overcome the loss by using more hip torque.

The reinforcement learning AFN controllers required approximately 150 trials to converge to a solution. The resulting control strategy was similar to the optimized open-loop and supervised learning AFN controllers.

When fatigue was simulated by reducing quadriceps muscle output by 40%, the reinforcement learning controllers initially failed. However, after 20 trials, they converged to a new solution which provided higher hip torque at the initial swing phase and produced successful gait. When given significant variations in body mass and geometric parameters, the reinforcement learning controllers converged to new solutions in usually less than 30 trials.

DISCUSSION

The supervised learning AFN controllers are similar to the open-loop controller, but have the advantage of closed-loop control. This was seen when fatigue was simulated.

The feasibility of reinforcement learning with an AFN was demonstrated. Although a specific biomechanical model was used representing a specific implementation of a hybrid FES orthosis, the control method is general purpose. The method requires no knowledge of the neuromuscular plant and can automatically adapt to biomechanical differences between patients and time varying changes such as muscle fatigue. The reinforcement learning controllers' use of partial training to re-adapt to new patients is practical for clinical application. In contrast to non-adaptive fuzzy logic networks [10], the teaching does not require a human expert to handcraft the fuzzy rules.

Further work is now underway to demonstrate the feasibility of the reinforcement learning AFN controllers in clinical application.

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SINGLE SWITCH MOUSE CONTROL INTERFACE

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ABSTRACT

This paper presents the first results from an experimental single switch direct manipulation interface. This interface is based on goal directed movements. The experiment focuses on the goal of target capture in a graphical user interface. Descriptions of the system and the experiment are also given.

INTRODUCTION

Direct manipulation lies at the heart of a graphical user interface. The importance of direct manipulation and its relationship to GUIs has been previously described[1][2]. The main advantage of direct manipulation is that it allows the user to become involved in carrying out whole actions and tasks rather than having to break tasks down into small, sometimes seemingly unrelated, parts. For example, systems that employ on screen scanning menus may require a user to scan through multiple levels to carry out a given task. The previous example illustrates why current systems that provide single switch access to GUIs are unable to provide all of the benefits of direct manipulation to the user. In an effort to improve single switch access systems to graphical user interfaces (GUIs), a new mouse pointer control scheme is being developed and tested. The concept of goal directed movement lies at the heart of this new control method.

BACKGROUND

A survey has identified a number of features that would make a computer more accessible to individuals with disabilities [3]. One of the features listed in this survey is software access to the operating system. Having access to the operating system not only allows software to interject information, such as simulated keystrokes, but allows a program to find out information about the environment in which it is running.

The driving force behind this control scheme comes from the desire to increase a user's control over direct manipulation while using a single switch interface [4]. To achieve this desire, a new control scheme for cursor control was proposed. At the heart of this new cursor control scheme is an intelligent software agent. The job of this intelligent agent is to perform tasks under the supervision of the user.

SYSTEM DESCRIPTION

The developed control method and interface differ from existing single switch GUI interfaces in a number of ways:

- the user is in control of a task, such as moving the mouse pointer to a target, rather than controlling a subtask, such as moving the mouse pointer in a particular direction,
- the task is carried out by an intelligent agent,
- the intelligent agent is knowledgeable about the environment it is working in,
- changing to a new task is initiated by the user and then carried out by the intelligent agent.

By using this interface a user supervises the actions of the control agent. To activate the control agent, a user supplies an appropriate 'GO' signal. In the case of our experiment, this signal comes in the form of holding down the right mouse button. If the user finds the control agent carrying out the correct task, she/he merely continues to supply the 'GO' signal. As long as the system sees a 'GO' signal it will continue with what it thinks is the appropriate task. If, however, the currently executing task is not the one desired by the user, he/she can terminate the 'GO' signal by releasing the right mouse button. This stops the current task. Pressing the mouse button again causes two things to occur:

- the intelligent agent re-evaluates the situation and attempts to come up with a reasonable choice for the task to perform,
- the intelligent agent begins to carry out the newly identified task.

The system uses information about the environment and the user's input to make its decisions about which task to execute. Due to the nature of Microsoft Windows, the environment for which this interface is developed, information about the objects on the screen is available [5].

EXPERIMENT DESCRIPTION

In order to test the ideas behind the proposed single switch mouse control interface (SSMCI), an experiment was designed and carried out. The experiment simulates the task of moving the mouse cursor to a target on the screen. The experiment begins with the presentation of a number of identical looking circular targets. After a short delay, one of the targets changes color, indicating this target as the goal target. Once the goal target is indicated, the user must then move the mouse pointer to the goal target. Moving the mouse pointer is accomplished by one of two control

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methods: the SSMCI and the arrow keys found on the numeric keypad[1]. Figure 1 is an example of a sample experiment screen. This figure shows a total of four possible targets and a mouse pointer. The number of targets on the screen varies from two to five throughout the experiment. The experiment was designed in such a way to guarantee equal number of trials with two, three, four, and five targets. The positions of the targets are random. While participating in the experiment, each subject saw a total of 200 trials. Of these 200 trials, 100 were conducted using the directional keys while the remaining 100 trials were done using the SSMCI. The trial scenarios seen by a user while using the SSMCI were the same as those seen while using the directional keys. The order of trial presentation, however, was random There were a total of eight subjects in this study. Of those eight, five were able bodied while three had different disabilities: cerebral palsy, C5-6 spinal cord injury, and Arthrogryposis Multiplex Congenita. All of the able bodied test subjects typically use a mouse while interacting with a computer. Those with disabilities, however, all used different methods (i.e. trackball, mouse, and directional arrow keys) for interacting with a computer on a daily basis.

Data was collected while the experiment was in progress. The data collected includes:

- total time required to reach the goal target,
- total distance travelled by the mouse pointer while reaching the goal target,
- distance the goal target initially was from the mouse pointers position,
- total number of key or switch activations made while reaching the goal target,
- in the case of the SSMCI method, the total number of intermediate targets chosen by the intelligent agent before the goal target was reached.

RESULTS

Once the data was collected, the two methods were compared to judge how well they performed in the task of target capture. Figure 3 shows the data collected concerning the average number of switch hits and key presses required by the able bodied users to reach the goal target. Figure 2 shows the average time required to capture the target by the able bodied subjects. For the data in Figure 2 and Figure 3, a one way ANOVA was performed which resulted in a $p << 0.001$. In Figure 4 the average number of switch hits and key presses is shown for the test subjects with disabilities. Figure 5 shows the average target capture times for the subjects with disabilities. As in the case for Figures 2 and 3, a one way ANOVA was performed which resulted in a $p << 0.01$.

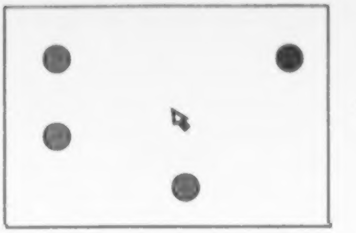

Figure 1: Sample experiment screen

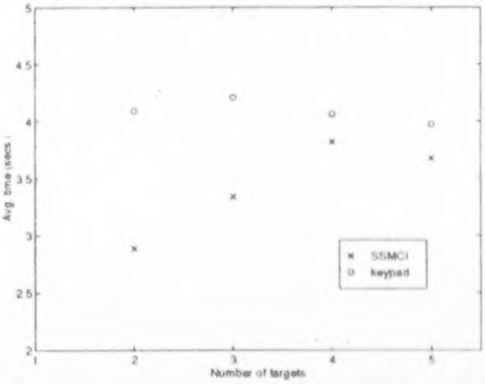

Figure 2: Average target capture time for able bodied subjects

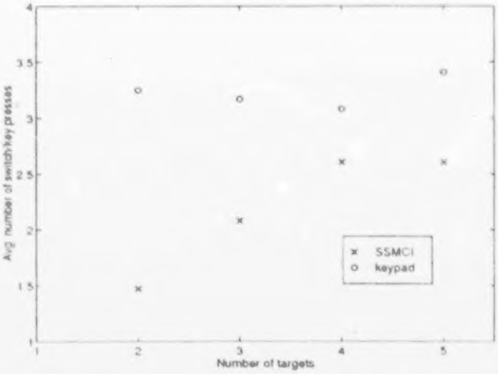

Figure 3: Average number of switch/key presses for able bodied subjects

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[1] With the proper software, the numeric keypad allows for 8 directions of movement: up, down, right, left, and 4 diagonal directions.

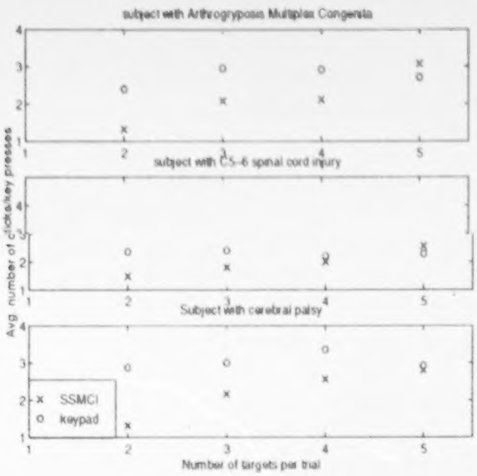

Figure 4: Average number of switch/key presses for subjects with disabilities

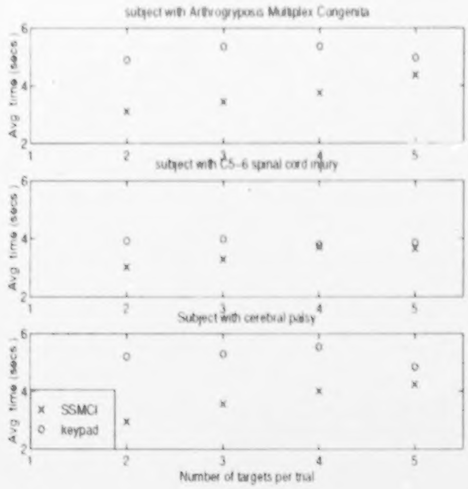

Figure 5: Average target capture times for subjects with disabilities

DISCUSSION

The above figures show a performance gain for the SSMCI when compared to the directional keys for the given task. This performance gain may be due in part to a number of factors:

- the intelligent agent alleviates the user from some of the burdens (mental and physical) associated with the task.
- by knowing the final destination, the SSMCI can move the mouse pointer at a faster velocity than if it were being controlled by hand.

By knowing the location of the targets, the SSMCI is able to plot a direct path to the target. Using a system that only allows selection of movement directions typically forces a user to move along an indirect path. Knowing the final destination also allows for velocity profiling. The current velocity profile includes both periods of movement at a constant velocity as well as periods of acceleration and deceleration. Since the SSMCI is able to decelerate to a slow speed as it approaches a target, it is able to travel at high speeds for the majority of travel towards the goal target. After completing the experiment, a number of subjects remarked that the SSMCI made the task easier. These subjects felt that acting as a supervisor to the SSMCI was easier than dealing with controlling the cursor movement themselves.

Future studies with the SSMCI could look at a number of issues including:

- improving the intelligence of the agent to make it more robust,
- looking at how the SSMCI performs in a more complex world,
- adding features to allow interaction with windows, menus and buttons.

Further performance gains and added functionary may be achieved through improving the intelligent agent. In is current form, it acts as a rule based planner.

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SINGLE POINT CENTER OF PRESSURE FOR WHEELCHAIR PROPULSION

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Abstract

Wheelchair propulsion is inherently a three dimensional activity without a single plane of analysis appropriate for all circumstances. Unfortunately, there is not a general solution for a three dimensional center of pressure (COP). Therefore, a least squares solution is sought. The COP is the point where the measured force applied by the hand to the pushrim would result in the measured moment. An algorithm is developed for the determination of an optimal single point COP by use of the pseudoinverse (Moore-Penrose inverse) and implemented in MatLab [2]. Kinetic data were collected from eight subjects using the SMART^{Wheel} [1,4], and kinematic data were collected using a PEAK5 video analysis system. The center of pressure is displayed graphically relative to the hand. Each graph may be rotated dynamically by the program user.

Introduction

Currently there are many figures of merit used for the biomechanics of wheelchair propulsion, many of which are analogous to those used in the analysis of ambulatory gait. These measures include the three-dimensional reaction force and moment at the hand, the calculation of forces and moments at the extremity joints, various time intervals, and the center of pressure (COP). The focus of this paper is on the development of a single point 3-D COP for wheelchair propulsion much like the 2-D COP used for the study of ambulation. Recently, a multiple COP measure for wheelchair propulsion was introduced by Cooper, et al. [1]. The calculation of the COP using this multiple COP definition is dependent on the particular plane used for the analysis. This same restriction applies to the COP definition used with force plates. Force plate COP calculation is a simplified case with the transverse plane passing through the center of the plate. Because the foot is incapable of exerting a pure moment onto a force plate, this restriction has not been recognized as a limitation. When used for the analysis of wheelchair propulsion, multiple planes are necessary due to the inherently three-dimensional nature of wheelchair propulsion, and the ability of the hand to exert a pure moment onto the pushrim. Since the direct calculation of a single point COP for three-dimensional Cartesian space is not possible for an arbitrary applied moment and force, an optimal solution was sought.

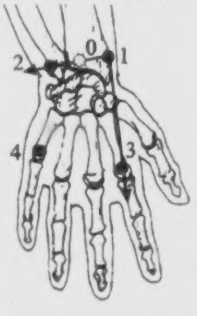

Figure 1 - Anatomical marker positions (dorsal view)

Methods

Single Point COP

As described in Cooper et al. [1], the COP is a point where the applied force by the hand onto the pushrim produces precisely the moment measured at the hub of the pushrim. Like a force plate, the direct calculated COP is restricted to a prescribed plane. The moment perpendicular to the prescribed plane is ignored, as well as forces parallel to the plane. By rotation of the prescribed plane, other force and moment components can be made to contribute. A single plane of analysis for wheelchair propulsion is not readily apparent. It would be desirable to find a single point in space which could represent the COP in all planes. Unfortunately, such a solution requires that the force vector and the moment vector be orthonormal [1].

The basis for the optimal solution is the use of the pseudoinverse (also called the Moore-Penrose inverse) [2]. Therefore, in order to proceed to the solution, the problem must be posed in matrix form defined on a local coordinate system based on anatomical markers on the hand is used. Figure 1 shows the locations of the four physical markers used (labeled 1, 2, 3, and 4), and the origin is defined as the midpoint between markers 1 and 2. The basis vector **j'** is chosen to be the vector from marker 1 to marker 2 ($\mathbf{R}_{12}$) normalized. The components of this vector are defined in Eq. 1.

$$\mathbf{j}' = \frac{\mathbf{R}_{12}}{|\mathbf{R}_{12}|} = \frac{(x_2 - x_1)\mathbf{i} + (y_2 - y_1)\mathbf{j} + (z_2 - z_1)\mathbf{k}}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}} \qquad (1)$$

Equation 2 describes vector **k'**. This vector is the basis vector of $\mathbf{R}_{13}$ made orthogonal to **j'** by subtracting off the component of $\mathbf{R}_{13}$ which is parallel to **j'**. This procedure is similar to the Gram-Shmidt orthogonalization procedure [2] which is used to produce an orthogonal matrix from a matrix of linearly independent vectors.

$$\mathbf{k}' = \mathbf{R}_{13} - \frac{\mathbf{R}_{12} \cdot \mathbf{R}_{13}}{|\mathbf{R}_{12}|^2} \mathbf{R}_{12} \qquad (2)$$

i' is defined be the cross product of **j'** and **k'** and the components are given by Eq. 3. Given this definition, **i'** will be normal to the plane formed by markers 1, 2, and 3, and point towards the dorsal side of the hand.

$$\mathbf{i}' = \mathbf{j}' \times \mathbf{k}' \qquad (3)$$

With the definition of the local hand coordinate system, any vector **R** in the global coordinate system can be described in the local hand coordinate system by Eq. 4.

$$\begin{bmatrix} R'_x \\ R'_y \\ R'_z \end{bmatrix} = \begin{bmatrix} i'_1 & i'_2 & i'_3 \\ j'_1 & j'_2 & j'_3 \\ k'_1 & k'_2 & k'_3 \end{bmatrix} \begin{bmatrix} R_x - x_0 \\ R_y - y_0 \\ R_z - z_0 \end{bmatrix} \qquad (4)$$

Equation 5 represents the cross product of **R** and **F** in a global coordinate system. This is precisely the definition of a moment, **M** produced by a force, **F** applied at **R**. The solution of Eq. 5 for **R** is the location of the COP [1]. There is no direct solution to this set of equations. The lack of solution is due to the fact that the matrix of the components of **F** is not invertable. It is readily apparent that the determinant of this matrix is zero due to the diagonal of zeros.

$$\begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} 0 & F_z & -F_y \\ -F_z & 0 & F_x \\ F_y & -F_x & 0 \end{bmatrix} \begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix} \qquad (5)$$

To calculate the COP in the local hand coordinate system instead of the global coordinate system, a substitution is made for **R** (Eq. 6). The substituted terms are from the solution of Eq. 4 for **R** in terms of the components of **R'**. Since the matrix of unit vectors is orthonormal, the inverse is simply it's transpose. Manipulation of Eq. 6 leads to a form which is similar to Eq. 5, but in terms of the local hand coordinate system. Let the 3x3 matrix in Eq. 6 be defined as **A**. Then **A** can be decomposed into two orthogonal matrices **U** and **V**, and a diagonal matrix (**S**) of the singular values of **A** (Eq. 7) by using singular value decomposition [2]. The pseudoinverse of **A**, denoted as $\mathbf{A}^{+}$, is then also given by Eq. 8, and the estimate of the single point COP location is given by Eq. 9.

$$\begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} 0 & F_z & -F_y \\ -F_z & 0 & F_x \\ F_y & -F_x & 0 \end{bmatrix} \left(\begin{bmatrix} i'_1 & i'_2 & i'_3 \\ j'_1 & j'_2 & j'_3 \\ k'_1 & k'_2 & k'_3 \end{bmatrix}^T \begin{bmatrix} R'_x \\ R'_y \\ R'_z \end{bmatrix} + \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} \right) \qquad (6)$$

$$\begin{bmatrix} M_x - F_z y_0 + F_y z_0 \\ M_y + F_z x_0 - F_x z_0 \\ M_z - F_y x_0 + F_x y_0 \end{bmatrix} = \begin{bmatrix} F_z i'_2 - F_y i'_3 & F_z j'_2 - F_y j'_3 & F_z k'_2 - F_y k'_3 \\ -F_z i'_1 + F_x i'_3 & -F_z j'_1 + F_x j'_3 & -F_z k'_1 + F_x k'_3 \\ F_y i'_1 - F_x i'_2 & F_y j'_1 - F_x j'_2 & F_y k'_1 - F_x k'_2 \end{bmatrix} \begin{bmatrix} R'_x \\ R'_y \\ R'_z \end{bmatrix}$$

$$\mathbf{A} = \mathbf{USV}^T \qquad (7)$$

$$\mathbf{A}^{+} = \mathbf{VS}^{-1}\mathbf{U}^T \qquad (8)$$

The pseudoinverse method finds an optimal solution for the COP ($\hat{R}$) in a least squares sense.

$$\begin{bmatrix} \hat{R}'_x \\ \hat{R}'_y \\ \hat{R}'_z \end{bmatrix} = \mathbf{A}^{+} \begin{bmatrix} M_x - F_z y_0 + F_y z_0 \\ M_y + F_z x_0 - F_x z_0 \\ M_z - F_y x_0 + F_x y_0 \end{bmatrix} \qquad (9)$$

Experimental Protocol

Eight volunteers gave written consent for this experimental protocol. All of the subjects were experienced wheelchair users with a disability. Subject 8 had cerebral palsy (CP). Each of the remaining 7 subjects had a traumatic spinal cord injury (SCI). All of the subjects wore black fingerless gloves with reflective markers attached. The markers consisted of 6 mm Styrofoam balls covered with highly reflective tape. The reflective markers were placed on the dorsal side of the hand over the radial styloid, ulnar styloid, and the second and fifth metecarpophalangeal joints [3]. These positions correspond to markers numbered 1 through 4 respectively (Figure 1). To establish a reference, a 12 mm marker was placed at the hub of the SMART$^{\text{Wheel}}$ [1,4].

Each of the subjects pushed for 2 min at two different speeds. The 1.34 m/s test was performed first followed immediately by a 2.24 m/s test. The exception was Subject 1 who performed these tests at 0.89 m/s and 1.79 m/s. Data were collected during the last 15 seconds of each test period. All of the subjects propelled a Quickie GPV wheelchair with a seat depth of 0.41 m and a seat width of 0.41 m. This wheelchair was mounted on a dynamometer with the rollers free to rotate.

All of the data were collected from each subject's right side. The positions of the reflective markers were recorded through the use of a PEAK5 (PEAK5 Systems Technology, Inc.) video analysis system. Three cameras were used. The first camera was placed perpendicular to the sagittal plane in-line with the rear wheels. The second camera was placed at a 45° angle between the sagittal and frontal planes. The third camera was placed at a 45° angle between the frontal and horizontal planes looking down at the subject. The video data was sampled at 60 frames per second and filtered with a 6th order, zero-phase, Butterworth digital filter with a cutoff frequency of 6 Hz. The pushrim forces and moments were measured using a SMART$^{\text{Wheel}}$ [1,4]. The SMART$^{\text{Wheel}}$ was calibrated immediately before and after all tests. The pushrim force and moment data were sampled at 240 Hz per channel and filtered with a 3rd order, zero-phase, Butterworth digital filter with a cutoff frequency of 40 Hz. The time base for the video data was increased from 60 Hz to 240 Hz by means of linear interpolation. Five strokes were analyzed for each subject. The strokes were parsed manually by the inspection of all moments and forces plotted in the time domain. Synchronization between both SMART$^{\text{Wheel}}$ and the PEAK5 systems was achieved with an electronic pulse at the beginning of data collection. The data were reviewed following each test to ensure proper collection.

All of the equations have been implemented as a function using MatLab (MathWorks Inc.). The output is a graphical projection of the COP on the computer screen. This projection may be rotated by changing the elevation and the azimuth independently in 15° increments through the activation of graphical buttons located on the projection plot.

Results

Estimates for the moment about the wrist can be obtained by substituting the optimal single point COP components

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into Eq. 9. The mean square error of this estimate normalized by the mean square of the moment components is 10.2%. Figure 2 is a plot of the optimal single point COP from a pushstroke of Subject 1 at 1.79 m/s. Figure 2 is a plot of optimal single point COP for Subject 5.

Discussion

The beginning and ending values for the COP over a single propulsion stroke (or step for force plate data [5]) are generally not considered to be accurate due to the small magnitudes of the measured force and moment. Widely varying results have been obtained for two reasons [5]. First, when the forces and moments are small, the signal to noise ration is low. Second, the 2D-COP may become unstable due to a small moment component value in the denominator. With the optimal single point COP, the solution is nearly always numerically stable. Cases of non-convergence for the QR algorithm are rare [2]. All of the data in this study produced convergence.

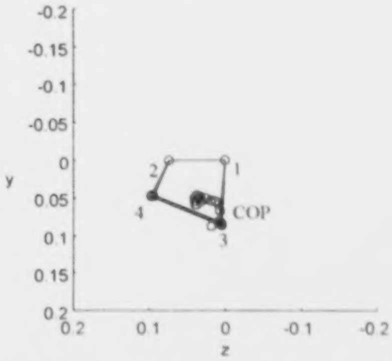

Figure 2 - Subject 1, 1.79 m/s. Location of COP overlaid on a plot of the hand markers. Line indicates back of hand. Dorsal view.

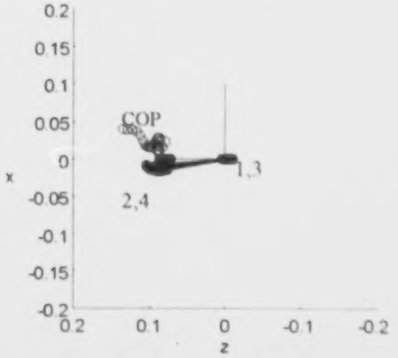

Figure 3 - Subject 1, 1.79 m/s. Location of COP overlaid on a plot of the hand markers. Line indicates back of hand. Frontal view.

The farther the single point COP is from the wrist, the greater the magnitude of the moment relative to the applied force. Large moments have been proposed to increase risk for CTS [6]. There are also examples where low force, high repetition activities can lead to increased risk for CTS. Wheelchair propulsion is clearly a highly repetitive task. Using the moment at the wrist does not take into account the anatomy of the individual, or the activity being performed. With the optimal single point COP, the moment is normalized by the applied force. Therefore, a larger individual may generate a larger moment at the wrist, but actually a smaller COP magnitude due to a larger applied force. Furthermore, an activity which produces low moments about the wrist may actually have high magnitudes for the COP due to a low applied force. The optimal single point COP could potentially be used as a measure to help optimize the propulsion stroke for the minimization of repetitive strain injury. The optimal single point COP may also prove to be highly intuitive feedback mechanism if graphed in real time with a superimposed image of the subject. The optimal single point COP can be visualized as the point through which the applied force is directed.

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THE EFFECT OF SHAPE FACTORS ON WHEELCHAIR CROSS BRACE STRENGTH

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Abstract

Cross braces are one of the primary failure points on a wheelchair. Four round and four rectangular cross braces were tested using an ISO Double Drum Tester. The round cross braces have been found to break occasionally within five years of purchase. The rectangular cross braces were made with a larger cross-sectional area and designed to retrofit the wheelchair frame. The purpose of this study was to test the cross braces to failure and measure the differences in strength between the round and square cross braces. Student t-tests were used to analyze the data. Rectangular cross braces were found to last significantly longer with $\alpha = 0.10$.

Background

A few studies have examined fatigue life of cross braces, and the stresses associated with fatigue testing. Peizer, *et al.* (1) studied the effects of destructive testing on a lightweight wheelchair. The chair was weighted with 200 pounds of shot bags and rolled off a 6 inch wooden platform repeatedly. Deformations of the frame were measured at regular intervals. At 38 cycles, both cross braces buckled. Baldwin and Thacker (2,3) studied strain based fatigue of wheelchairs on a double drum machine. Two wheelchairs were mounted with strain gages near the cross pin of the cross brace tubes and on the side frame behind the front caster. Although the wheelchairs were not tested to failure, estimates of the number of fatigue cycles to failure were made using a strain based fatigue analysis. Neither of these test high cycle fatigue however.

Objective

The cross-sectional area of a constant section cross brace is limited by the diameter of the upper and lower braces where the members are welded together. Other shapes, such as a tube with a variable section would be cost prohibitive. In order to change the size of the cross-sectional area, the shape of the cross brace must be changed. A square or rectangular cross brace can maximize cross-sectional area within the constraints of the connecting members and also be readily retrofitted onto the wheelchair frame.

The objective of this study was to obtain the number of failures for each type of cross brace and observe if changing the shape resulted in an increase in fatigue life. With this information, recommendations for further cross brace design could be proposed. Future design could result in stronger cross braces that last longer without reducing function.

Methods

The ISO Double Drum Test (4) was modified to apply more stress on the cross brace. The drums were offset from the centerline to simulate a sinusoidal road surface. The offset on the rear drums was 8 cm, and the offset on the front drums was 4 cm. This increased the cyclic stress on the cross brace. The Double Drum machine was run at a surface speed of 0.6 meters per second for the rear drums. The speed of the front drums is 7% faster to simulate pseudo-random phase between the rear and front drums. Two twenty five pound plates were bolted to the chair on both sides of the back of the frame next to the seat. Two additional twenty five pound plates were bolted to clamps attached to the footrests. Elastic cord was used to stabilize the and prevent tipping. Minimal tension was placed on the cords when the chair was stationary. Two cords were attached from the front of the chair to the front frame of the two drum machine. Another two cords were attached from the rear of the chair to the back frame of the two drum machine. Finally, the caster spindles were tightened to reduce caster swivel.

The wheelchair used in the test had a 49 cm seat width, a 41 cm seat depth, and a 54 cm wheel base. The rear wheels were standard 24 inch diameter, 1-3/8 inch wide pneumatic tires. The front casters were 18 cm solid type casters. A 100 kilogram ISO Standard Dummy was loaded in the wheelchair (5), see **Figure 1**.

The rectangular cross braces measured 1.0 inches by 1.4 inches with a thickness of 0.11 inches by 0.14 inches. The round cross braces measured 1.1 inches in diameter and had a thickness of 0.13 inches. Ashby (6) lists shape factors for the stiffness and strength of various shaped members. Each shape factor is normalized to a solid circular section. The equation for a circular hollow tube for strength in bending is:

$$[(2 \times \text{radius})/\text{thickness}].$$

The equation for a rectangular tube for strength in bending is:

$$\{(2\pi/9)(h/t)[(1+3b/h)^2/(1+b/h)^3]\},$$

where h = height, t = thickness, and b = base. Based on these equations, the rectangular cross braces are theoretically 44% stronger than the round cross braces.

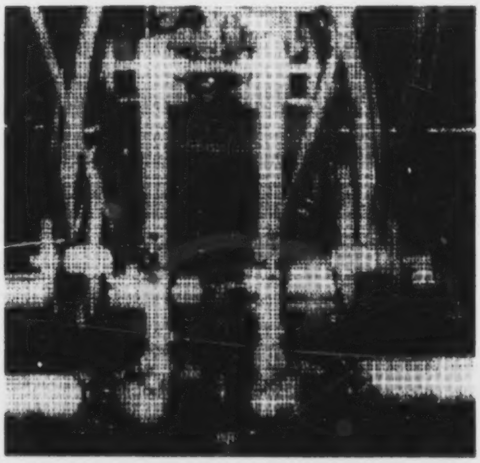

Figure 1 - Photograph of a test wheelchair with ANSI/RESNA-ISO 100 kilogram dummy secured to a Double-Drum tester. Supplementary weights are also visible.

Results

Table 1 illustrates the random testing order, cross sectional area, and number of cycles to failure for the eight cross braces.

Table 1- Results from Modified Double Drum Fatigue Testing.

Cross Brace Type	Cross Sectional Area	Number of Cycles to Failure
Round #1	0.95 in^2	33,015
Round #2	0.95 in^2	79,184
Rectangle #1	1.14 in^2	77,769
Round #3	0.95 in^2	162,522
Rectangle #2	1.14 in^2	169,816,
Rectangle #3	1.14 in^2	172,466
Round #4	0.95 in^2	29,329
Rectangle #4	1.14 in^2	>200,000

Two sample t-tests assuming unequal variances were run on the data. It was found the rectangular cross braces had a significantly larger number of cycles to failure ($\alpha < 0.10$). A significance level of $\alpha < 0.10$ was use to avoid missing differences in fatigue cycle life due to the low number of test samples.

Discussion

Fatigue causes a crack to develop usually at the bolt hole where the two braces are connected as in **Figure 2**. Once the crack has reached a critical length, fast fracture occurs severing the cross brace causing the wheelchair to collapse. Some fast-fatigue failures may be inconvenient to the wheelchair user as well as costly (7).

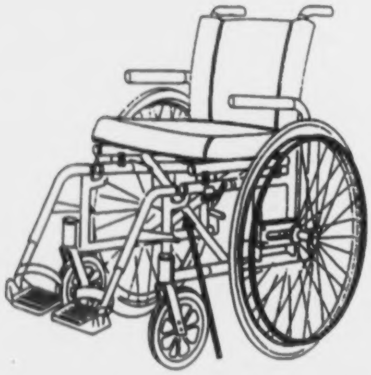

Figure 2 - Illustration of cross brace failure occurring on rehabilitation wheelchairs during fatigue testing. The arrow marks the area where breakage occurs.

The data from the two drum test indicate the rectangular cross braces are stronger and more durable than the round cross braces. The mean fatigue life (number of cycles to failure) of the rectangular cross brace was nearly twice that of the round cross brace. One of the round cross braces had a fatigue life similar to that of the rectangular cross braces, and one of the rectangular cross braces had a fatigue life similar to that of the round cross braces. These results indicate that on average, wheelchairs will last longer with the rectangular cross brace design, but there will be variability in the fatigue life of an individual chair.

To provide further analysis strain gages will be mounted on the cross braces to obtain cyclic stress values. High-cycle fatigue analysis will be performed with the strain gage data to provide a tool for predicting cross brace fatigue life. The validity of this tool for predicting cross brace failure will be tested by correlating the theoretical fatigue data with the failure data obtained from the double drum test described in this study. Considerations will also be made as to the sensitivity of the test on speed and the size of the drum slats.

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